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Mealiness and quality of Delicious apples as affected by certain orchard conditions and storage techniques

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MEALINESS AND QUALITY OF DELICIOUS APPLES AS AFFECTED BY CERTAIN ORCHARD CONDITIONS AND STORAGE TECHNIQUES

by

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I. INTRODUCTION

The Delicious apple* was discovered about 70 years ago by Jesse Hiatt on his farm near Peru, Iowa. In 1894 he transferred the propagating rights on the seedling variety to the Stark Brothers Nurseries and Orchards Company, Louisiana, Missouri, who saw in the new variety characteristics which recommended it for wide distribution. Time has proved that this judgment was justified.

A. Commercial Importance of the Delicious Apple

The Delicious apple is grown in practically all the apple areas of North America, but in greatest volume in the Pacific Northwest in the State of Washington. Gourley and Howlett (19) show that Delicious is the most heavily planted, and continues to be the most heavily planted variety of apple in the United States of America. Detailed records of production by varieties are not available for either the United States or Canada, but some idea of the comparative importance of this variety in relation to the total production of apples

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* In 1922 a memorial monument to commemorate the discovery of the Delicious apple was erected in the city park at Winterset, Iowa. The dedicatory exercises recorded in the Transactions of the Iowa State Horticultural Society, Vol.57 (1922), present a complete historical account of the variety. (38, 63, 70, 71)

for the United States can be gained from the following information supplied by the Agricultural Marketing Service, U. S. Department of Agriculture, Seattle, Washington (12): "The average production of striped and red strains of Delicious in the State of Washington for the period 1934-38 amounted to 30 per cent of the total apple production for the State and increased to 33 and 34 per cent respectively in 1939 and 1940. Considering the crop in commercial counties (including culls, home use, waste) the 1934-38 average production was somewhere less than nine million bushels." In the opinion of Stewart (64), the United States Delicious crop amounts to from 10 to 20 per cent of the total apple production, probably averaging close to 15 per cent.

Taking the average yearly production of apples in the United States for 1934-38, as 125,310,000 bushels (12), 15 per cent of this figure amounts to 18,796,000 bushels for Delicious, a truly amazing figure. Unless this figure is exceeded by the heavy production of Winesap from mature orchards throughout the country, for which statistics are not available, Delicious stands out as the leading commercial variety of apple in America. The weight of these figures lends emphasis to the importance of correct picking, handling, and storage methods for this variety.

B. Mealiness and Poor Quality, Common Faults of the Delicious Apple

The enormous crops of Delicious produced in recent years have made it necessary to store a large portion of the fruit in order to spread the marketing season. Frequently, Delicious have been over-stored, or stored at unsuitable temperatures. Moreover, failure to realize the perishable nature of this variety has led to carelessness in handling by retail distributors with the result that mealy overripe Delicious apples are constantly being offered for sale and often at premium prices. This situation is current wherever Delicious are sold, and is reacting unfavorably against the reputation of the variety.

A second factor which interferes with the popularity of Delicious is the fact that a large proportion of the Delicious grown are flat and insipid in flavor rather than possessing the peculiar piquant quality so characteristic of this variety at its best. This fact has been noted in both British Columbia and Iowa, and has been drawn to the author's attention by technical workers in the State of Washington as a condition commonly prevailing there.

The annual crop of Delicious is large and is steadily increasing. The continuation of a profitable market for this variety will depend upon consumer preference. To maintain this consumer preference, high quality Delicious, firm and juicy in texture, and aromatic in flavor, must be made available to the public. This investigation has been carried out to ascertain causes for mealiness and poor quality in Delicious, and to suggest means by which the handling and storage of Delicious may be improved to achieve this goal.

II. REVIEW OF LITERATURE

No detailed study of mealiness and quality in Delicious apples has, to the knowledge of the author, been reported upon. However, numerous studies on apple physiology and apple storage provide valuable information on phases related to the problem.

It is suggested by Magness and Diehl (41) that crispness in apples is due to the cementing effect of the calcium pectate (protopectin) contained in the middle lamellae of the cell walls. Hydrolysis of the protopectin to the soluble pectin form results in softening and ripening of the fruit. When an apple becomes overripe through extensive protopectin hydrolysis, it loses its juiciness and tastes mealy because in the process of mastication the teeth slip between the cells rather than rupturing them and releasing the juice. When it is mealy and soft, an apple actually contains nearly as much moisture as when it is hard and juicy, according to Magness and Diehl (41). Chemical determinations by Haller (20), Carré (7, 8), and Emmett (15) support this view. Similar studies carried out with other fruits such as pears, Gerhardt (18), and peaches, Appleman and Conrad (2), show amount of softening to be associated with degree of protopectin hydrolysis. Rate of softening in stored apples is proportional to the rate of soluble pectin formation, according to Haller (20), but relative firmness of different varieties of apples cannot be accounted for entirely by differences in their pectic constituents. Chemical estimation of the hydrolysis of protopectin to soluble pectin in apples has been outlined by Carré and Haynes (9) and this method, with some adaptations, is the one commonly used.

Various measurements of the progress of maturity of apples while still on the tree, and ripening of the fruit after removal from the tree and placement in storage, have been reported. Among other tests, respiratory trend, acid metabolism, firmness as measured by the pressure tester, skin and flesh color, ease of picking, starch disappearance as judged by the iodine test, and protopectin hydrolysis, have been used to gauge the ripening process.

It has been shown that respiratory trend is closely related to temperature and keeping quality of apples. Thus Bigelow et al (4) showed that rate of respiration increases with rise of temperature according to Van't Hoff's law. Harding (24) divided the respiratory trend of Grimes apples at 50° F. into four stages: (1) Period of accelerated ascent; (2) Period of rapid descent; (3) Period of gradual descent; and (4) Period of senescence. This same trend would follow for temperatures somewhat lower than this and also a great deal above 50° F. However, at 32° F. and 36° F., Harding (24), and Magness and Burroughs (40), report that fruit stored immediately respired at a very constant rate throughout storage and did not show the climacteric occurring at higher temperatures. Magness and Diehl (41) report steep increases in respiration intensity with increasing storage temperature which were closely related to rates of softening. Magness et al (43) report that respiration rate at 40° F. was almost double that at 32° F., while the rate at 60° F. was about three times that at 40° F. Kidd and West (30) report an inverse relation between respiratory activity and keeping quality of apples. They also report (34) that at 2.5° C., 10° C., and 22.5° C. total amount of carbon dioxide liberated and dry matter lost from harvest to death were approximately the same at all three temperatures.

During storage, sugar and acid are respired by fruit. The higher the temperature at which the fruit is held, the higher is the loss of acid. Magness et al (43) working on the respiratory ratio of apples found that at 32° F. there was approximately equal oxidation of sugar and acids, at 40° and 60° F. sugars mainly were oxidized and at 85° F. there was a somewhat greater oxidation of acids. Magness and Diehl (41) found that all varieties showed a constant decrease in acidity during the time the apples were held in 32° F. storage. Rate of decrease was nearly the same in all varieties regardless of acid content. In six months' storage, Delicious lost roughly one-third of its acid. Plagge et al (53, 54) also report losses of acid in storage increasing with length of storage and degree of temperature. They found (53) that two factors influence total acid lost: initial acid content when stored, and storage temperature. They found that the amount of soggy breakdown and Jonathan spot which occurs in storage is in inverse proportion to acid loss during storage, and that a storage temperature of 36° F. which induces higher acid respiration reduces losses from breakdown.

The pressure test as a gauge for maturity of apples has met with varied acceptance. Hartman (27) cautions that the pressure test may be influenced by factors such as temperature of the fruit, turgidity, removal of a portion of the crop, amount of russeting, and intensity of "over" color, and concludes that in most cases decrease in firmness is not sufficiently indicative to be a reliable guide for time of picking. Haller and Harding (21) report that apples grown under ample moisture conditions are softer than those grown under dry conditions. Magness et al (43) consider the pressure test of value mainly as a guide to avoiding overripeness. Plagge et al (54) conclude that: "The optimum picking time for Grimes cannot be detected by noting differences in resistance offered by fruit as measured by the pressure tester."

Magness et al (42) conclude that fruit pressure is one guide to picking maturity and set forth ranges of formness for optimum picking of different varieties: for Delicious, 18 to 16 pounds. Using the pressure tester, Magness and Diehl (41) report rate of softening in storage at 32° and 70° F. for different varieties: for Delicious they found that the fruit was softer at the end of twelve days at 70° F. than after six months at 32° F. Magness and Taylor (44) set forth in tabular form the approximate pressure ranges for picking, prime eating condition, and overripeness of fourteen different varieties of apples, but add that these figures vary with growing district and other factors. Most recently, Haller et al (23) report that with apples each stage of ripeness is represented by a fairly definite range of firmness, and that the pressure tester is a valuable supplementary method for determining accurately the stage of ripeness of apples.

Changes in skin and flesh color in apples may be useful guides to picking maturity. Thus Palmer and Strachan (48) showed with both red and striped Delicious that there was a marked correlation between greenness of flesh color, low amount of red skin color, and lack of maturity. Strachan (65) further amplified these experiments and devised a color chart showing the correct shade of flesh color for harvesting Delicious. Corbett (11) suggested flesh color as a guide to picking Rome Beauty. Davis (13) published a chart showing color shades of skin ground color for picking McIntosh and Fameuse. Magness et al (42, 43), and Plagge et al (54) have presented color charts based on changes in ground color of the skin as guides to picking maturity. All investigators of fruit maturity indices point out that in addition to other tests, color of seeds and ease of separation from the spur are guides to picking maturity.

The starch-iodine reaction for gauging the ripening process in apples was first studied by Bigelow et al (5) in 1905. They found that the starch first disappeared within the core-line of the fruit while it remained longest in the outer three millimeters of the cortex, and in V-shaped areas extending outward from the fibrovascular bundles emanating from the stem. The starch-iodine reaction has been studied more recently by Australian and New Zealand workers as a picking maturity test for apples. Carne et al (6) state that "the iodine-starch reaction is a simple and effective means of recognizing the picking maturity of an apple, provided the test is made shortly after the apple is removed from the tree." For this they set out certain standards for measuring starch disappearance. They found that disappearance of starch as measured by chemical analysis coincided with changes in the starch-iodine picture. Hesse and Hitz (28) also report a correlation between loss of starch and increase in maturity for Jonathan apples. Davis and Blair (14) worked out a series of starch-iodine pictures to serve as a guide for picking McIntosh and Fameuse apples, but found it necessary to qualify their application depending on nutritional status of the trees on which the fruit was produced. Tiller (67) made an extensive study of the starch-iodine test for maturity of apples, and owing to the variability he discovered within given lots of fruit, was inclined to discredit the value of this test for practical purposes. In none of the varieties he worked with did he find it possible to predict the extent of starch conversion from a consideration of ground color or other ascertainable characteristics. With Delicious in particular he states the following regarding the iodine test for picking maturity:

1. Disappearance of starch commences from the center of the core and extends outwards very slowly.
2. Starch loss is generally of a very low order.
3. There is only very slight alteration in starch content over a long period.
4. Considerable variation in starch content occurs from fruit to fruit.

In extending the storage life of apples all investigators have stressed the importance of prompt cold storage at 32° F. after picking. This is well illustrated by the work of Magness et al (41, 43) who show the relation of temperature to softening. Exceptions to this statement are found in the work of Plagge et al (56), and Plagge and Maney (55) who recommend a temperature of 35° to 36° F. for apples, Overholser et al (47), and Ballard et al (3), who recommend storage of California Newtowns at a temperature of 37° to 40° F. to avoid internal browning, and of Kidd and West (31) who recommend a storage temperature above 32° F. for several varieties. More recently, Plagge (52) re-opened the question of correct storage temperatures for apples by stating that they should be stored at 35° F., citing improved eating quality and reduced storage disorders as a result. For some varieties such as Delicious, opinion is not unanimous regarding this recommendation. Thus Haller and Lutz (22) in 1941 state that from the results of their work ripening and softening of apples was generally much more rapid at 36° F. than at 32° F., and deterioration in dessert quality faster at the higher temperature Delicious showed a somewhat reduced storage life at 36° F. as compared with 32° F. Grimes was the only variety which responded better to a temperature of 36° F.

The storage of apples in controlled atmospheres (gas storage) in which the relative amounts of carbon dioxide, oxygen, and nitrogen vary from normal, has received much attention from research pomologists during the past fifteen years. The impetus to this work was supplied by Kidd and West who in 1927 published their first treatise (37) on the subject. In this they described their preliminary work dealing only with controlled ventilation gas storage, which showed marked extension of storage life for apples, notably with the Bramley Seedling variety. In this article they reported better preservation of green color, greater firmness and juiciness of the fruit, and increased storage life of fruit in gas storage as compared with air storage. They further showed that controlled ventilation gas mixtures at 39o F. owed their efficacy for storage not only to the increase in carbon dioxide, but also to the reduction in oxygen content. Another publication (33) in 1930 dealt with optimum temperatures and atmospheres for Bramley Seedling, and showed that the efficacy of "gas storage" was governed by the relationship between carbon dioxide, oxygen, and temperature. Optimum storage conditions for this variety consisted of 10 per cent oxygen and 10 to 15 per cent carbon dioxide at a temperature of 41° F.

Proceeding to another phase of controlled atmosphere storage, Kidd and West (35) reported in 1933 that for Lane's Prince Albert apples, a gas mixture of 2.5 per cent oxygen, 5 per cent carbon dioxide, and 92.5 per cent nitrogen at 39° F. doubled storage life of this variety as compared with air storage at the same temperature. Maintenance of such a gas mixture required a carbon dioxide scrubber as well as restricted ventilation. In 1935, Kidd and West (36) published a more complete treatise on gas storage in which they reported recommendations for storage of fourteen different varieties. This report deals with maturity and treatment of fruit before storage, construction and operation of storages, costs, etc. Construction and management of controlled atmosphere storages has also been dealt with by Van Doren (69), Hardy (26), and Phillips (50).

Controlled atmosphere storage experiments with different varieties from those grown in England have been carried out in North America. Allen and McKinnon (1) working with California Newtowns at 40° F. reported greatly improved keeping quality, retention of ground color and flavor with a 10 per cent oxygen : 10 per cent carbon dioxide mixture. Phillips (51) in Ontario, reports improved keeping quality of McIntosh and elimination of core flush by storing this variety in a 7 per cent carbon dioxide mixture at 40° F. as compared with air storage at 32° F. Smock and Van Doren (62), working with McIntosh and Cortland in New York, report that a controlled atmosphere of 2.5 per cent oxygen and 5 per cent carbon dioxide at 40° F. greatly improved length of keeping life compared with ordinary cold storage. Their results with other varieties including Wealthy, Jonathan, and Baldwin, using this same gas mixture, were not so favorable because of brown core or scald development. An atmosphere of 5 per cent carbon dioxide : 2 per cent oxygen for Delicious showed a slight improvement in keeping quality over air treatment. It has been reported by Fisher (16) and confirmed by Phillips (51) that atmospheres containing carbon dioxide are likely to be injurious to Delicious, and that best results are obtained with a mixture of 2.5 per cent oxygen and 97.5 per cent nitrogen.

Van Doren (68) reports a diminished rate of softening and protopectin hydrolysis in McIntosh apples stored in controlled atmospheres as compared with air. Similar results for various fruits were reported by Smock and Allen (60). Kidd and West (32) report that in a "natural build-up" atmosphere of 12 per cent carbon dioxide : 9 per cent oxygen, respiration was approximately halved as compared with that in air. Thornton (66) has reported the effect of high concentrations of carbon dioxide for short periods upon fruits and vegetables held at different temperatures. Miller and Brooks (45) found no significant differences in the carbohydrate fractions of different fruits subjected to high concentrations of carbon dioxide for short periods as compared to similar fruits stored in air. Kidd and West (35) have reported small differences in carbohydrate fractions of fruits resulting from different controlled atmosphere treatments.

Improving the storage life of apples by application of waxes, oils and emulsions of these materials to the skin of the fruit have been reported upon by several investigators. Magness and Diehl (41), using oil and paraffin coatings, showed that these substances reduced the permeability of the epidermis, rate of respiration, rate of softening, and delayed the change of skin color from green to yellow. Such retardation in rate of ripening was at the expense of flavor unless the coatings were very light. Coatings so light as not to injure the flavor of the fruit caused only a very slight retardation in the softening process. Even very thin coatings resulted in bad flavor in certain varieties, particularly when such varieties were exposed to high temperatures.

Smock (59) using commercial wax preparations on apples and pears held at 65° F., found a marked reduction in respiration rate of the treated fruit accompanied by a striking increase in carbon dioxide in the internal atmosphere of the fruit. Rate of ripening was also retarded. However, when waxes were applied in sufficient quantity to retard ripening materially, abnormal flavors resulted.

Hitz and Haut (29) studied the effect of several commercial wax emulsions on Golden Delicious and Grimes Golden apples held in cold storage. Throughout their experiments they found that waxing reduced the percentage of wilting. Waxing immediately after picking induced scald and abnormal flavors, but after a delayed storage period of one week at 57° to 60° F. fruit thus treated showed decreased wastage in comparison with untreated fruits placed in cold storage immediately after picking. Such differences in shrinkage as were obtained in favor of waxing were relatively slight, the reduction in shrinkage being roughly of the order of 1 per cent of the fresh weight of the fruit.

Claypool (10) reported the chief benefit to fruit from waxing was retardation of water loss. Fisher and Britton (17) reported that under conditions of low humidity, waxing reduced shrinkage materially, lowered respiration intensity, delayed onset of mealiness in Delicious, and reduced core flush in McIntosh and Jonathan spot on Jonathan.

III. EXPERIMENTAL

A. Scope of Investigation

Soon after starting this project it became apparent that the problem of mealiness and poor quality in Delicious had wide ramifications which necessitated various angles of approach. The development of mealiness in Delicious apples in storage, for example, was found to be related not only to storage conditions, but also to conditions under which the fruit was grown and harvested. Furthermore, Delicious with flat insipid flavor were found to be so common in occurrence that it appeared that poor quality in this variety could be attributed as much to this factor as to mealiness itself. Thus in the development of the investigation, it was necessary to approach the problem from the growing end as well as from storage and laboratory aspects.

B. Methods of Procedure in Orchard, Storage, and Laboratory

Many of the results described under the different phases of this investigation required the same experimental methods. In order to avoid needless repetition in describing the techniques used the different procedures used have been divided into those employed in (1) orchard, (2) storage, and (3) chemical laboratory.

1. Orchard

Selection of samples. Where comparative treatments were being carried out, care was taken to select fruit of specified size and color percentage. Usually, medium sized, Extra Fancy apples were used. Fruit for an experiment was always selected either from a single healthy representative tree or consisted of a sample made up from equal numbers of apples from several trees.

Preparation for storage. Except where otherwise noted, the fruit was placed in storage within a day or two of picking. The fruit was usually stored loose unwrapped, so as to permit a maximum development of apple scald in susceptible lots.

2. Storage

Pressure test. The pressure test was taken on a sample of ten representative fruits by means of the standard Ballauf pressure tester designed by Magness and Taylor (39). Before taking the test, two slices of skin on opposite cheeks of the apple were pared off at the points where the pressure test was to be taken. Pressure tests were all taken by the same operator, so as to eliminate differences in results usually obtained when different individuals work on the same material.

The storage rooms. The storage rooms used for holding the fruit were maintained at temperatures of 32o, 40°, and 60° F. In all rooms the humidity was maintained at a level of between 80 and 90 per cent of saturation. In the 32° and 40° rooms temperatures were maintained constant within one degree by brine circulation refrigeration coils in each room with electric fans to circulate the air. The 60° room is a well insulated basement cold storage which is maintained at a temperature close to 60° in cold weather by means of a small electric heater, and by adjustable ventilation ports.

Waxing of apples. Apple waxing experiments were performed for three seasons using waxes supplied by a commercial company. The waxing material was applied as a dilute solution consisting chiefly of paraffin wax (melting point 130), carnauba wax, and triethanolamine or sodium oleate as an emulsifier. The apples were dipped in the wax emulsion maintained thermostatically at a temperature of 105° F., and then spread out on newspapers to dry overnight. They were then wrapped and placed in storage.

Controlled atmosphere storage experimental technique. Controlled atmospheres are explained as follows: The composition of normal air is roughly 79 per cent nitrogen, 20 per cent oxygen, and 1 per cent of argon with traces of carbon dioxide and other gases. Controlled atmosphere storage is obtained by enclosing the fruit in a sealed chamber, and permitting it through the process of respiration to change the composition of the air by depleting the oxygen and converting it into a similar volume of carbon dioxide, according to the formula for the oxidation of sugar:

$$C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O + 677.2 \text{ calories}$$

$$1 \text{ molecule} \longrightarrow 6 \text{ molecules} + 6 \text{ molecules} + \text{energy.}$$

Thus, if 8 per cent of the oxygen is removed in respiration, 8 per cent of carbon dioxide will have been produced, and the storage atmosphere will consist of 12 per cent oxygen and 8 per cent carbon dioxide. If when the carbon dioxide reaches a desired level, e.g. 8 per cent, sufficient outside air is then admitted to supply additional oxygen and prevent the carbon dioxide from accumulating above the 8 per cent point. This system can be called regulated ventilation-controlled atmosphere storage.

Controlled atmosphere storage, however, has been carried still further to meet the requirements of some varieties which respond better to lower percentages of oxygen than can be secured merely by regulated ventilation. With such varieties the storage atmosphere is allowed to become depleted of oxygen down to say 2.5 per cent, by respiration of the fruit. The corresponding increment in carbon dioxide produced by the respiration process is then absorbed by passing the air in the storage room through a sodium hydroxide scrubber solution regulated to maintain the carbon dioxide at a certain level, and prevent it from exceeding this point. A slow influx of air is admitted to hold the oxygen content of the air at the 2.5 per cent level. As oxygen is removed from the atmosphere, transformed to carbon dioxide, and the carbon dioxide absorbed by sodium hydroxide, the proportion of nitrogen in the atmosphere thus correspondingly increases. This is a more complicated application of controlled atmosphere storage.

The manipulation of the percentages of oxygen, carbon dioxide, and nitrogen in storage air requires a different technique for experimental work than is required in commercial application. For regulated ventilation storage experiments, about 8 kilograms of apples were enclosed in a 4 (Imperial) gallon wide-mouthed friction-top can. Two outlets were fitted into the lid of each can. The cans containing apples were placed under refrigeration and after several days built up concentrations of carbon dioxide through respiration to desired levels. These levels were determined by means of the Orsat gas analyser. Every other day, gas samples were withdrawn from the cans of fruit and analysed to determine how much carbon dioxide had accumulated over the desired level. This excess carbon dioxide was then removed by means of a small closed circulation electric blower which had adjustable apertures for drawing in new air and expelling old. This blower was attached to the two outlets on the can and run for a sufficient number of seconds to remove the excess of carbon dioxide to a point slightly below the desired concentration. Where, for example, it was desired to store apples in 7.5 per cent carbon dioxide, the actual concentrations covered a range of 6.5 to 8.5 per cent. Deviations from the desired carbon dioxide level, seldom if ever exceeded 1 per cent.

For controlled atmosphere experiments where carbon dioxide, oxygen, and nitrogen all had to be regulated, a different method for developing the artificial atmospheres was used. Here, the mixtures were made up from compressed cylinders of the three gases. Attached to each cylinder was a two-stage Hoke-Phoenix constant-pressure pressure reducer with a brass cross fitted into the delivery outlet which permitted three independent leads to be taken simultaneously from the same cylinder. Attached to each arm of the cross was a needle-valve which regulated closely the rate of flow of gas from the cylinder. This apparatus attached to a cylinder of oxygen is shown in Figure 1. Further precision in metering out the exact flow of gas was secured by means of capillary flow meters and bubble counters attached to the lines leading from the pressure reducers.

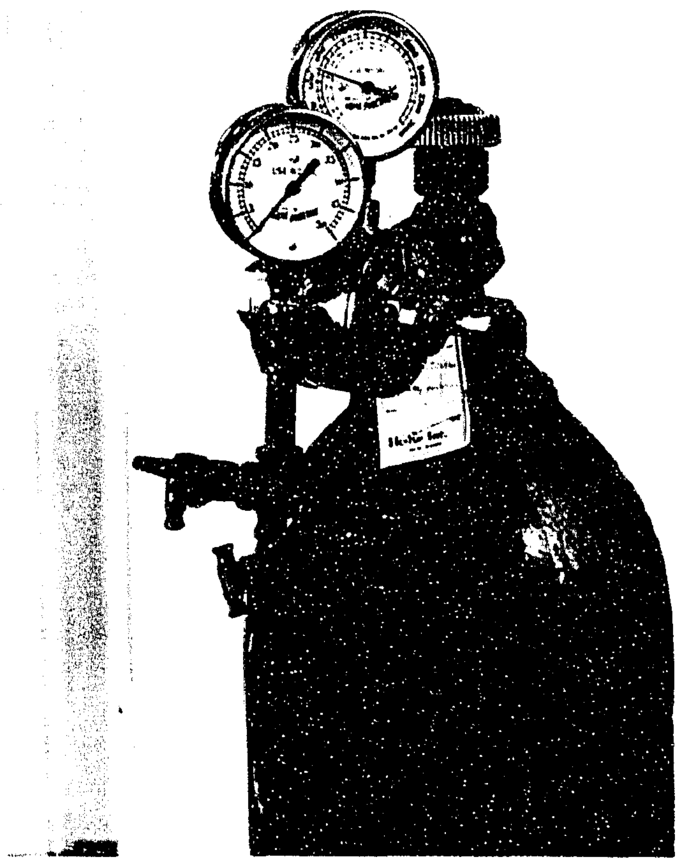


Figure 1. Hoke-Phoenix pressure reducer attached to compressed gas cylinder. Note brass cross with three independent needle-valve outlets.

In making up each gas mixture one lead was taken from each gas cylinder (nitrogen, carbon dioxide, and oxygen) into a 2000 cc. Erlenmeyer flask filled with glass wool. The intakes into the Erlenmeyer extended to the bottom of the flask, and the gases filtered up and became mixed before leaving the outlet tube from where the mixed gas flowed off to the apples stored in 4-gallon friction top cans. In the work carried out at Iowa State College wide-mouthed 5-gallon pickle jars were used with special tight-fitting lids equipped with inlet and outlet connections.

These gas mixtures were flushed continuously over the fruit at a rate sufficient to change the atmospheres in the containers twice a day. The pressure of gas released from the cylinders provided sufficient head to force the gas mixtures uniformly throughout the series of storage cans. A view of the gas mixing and delivery apparatus, and fruit storage cans is given in Figure 2.

Once set in operation this apparatus gave efficient and uniform control of the atmospheres. After reaching equilibrium, gas mixtures in the storage cans themselves were checked weekly with an Orsat gas analyser.

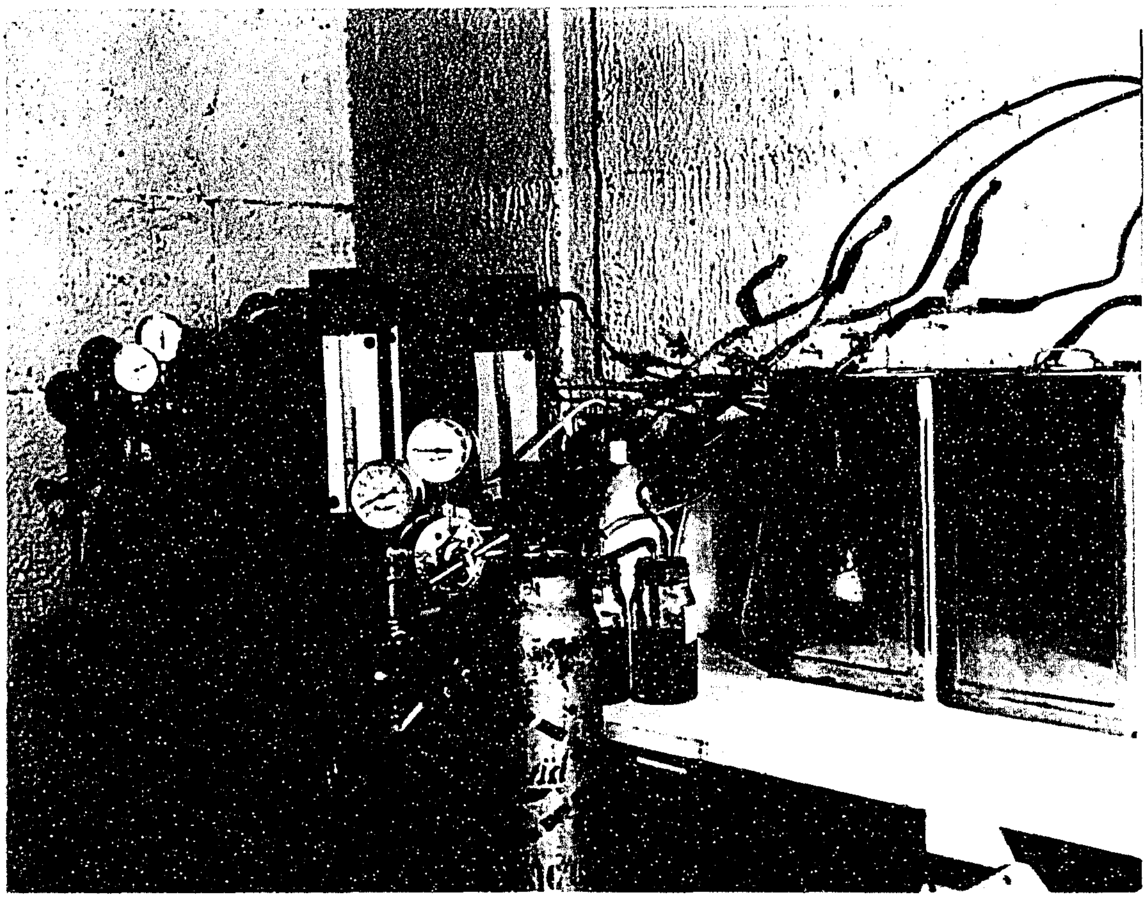


Figure 2. Gas mixing apparatus with delivery lines leading off to the various cans of enclosed fruit. Carbon dioxide cylinder front; nitrogen cylinder extreme left; oxygen cylinder at back.

3. Laboratory

Soluble pectin determinations. A juice sample was expressed from ten or more representative fruits by means of an electric centrifugal mascerator. The juice sample was then strained through a sieve or cheesecloth to remove the greater part of the suspended material. One hundred cc. of the juice was then pipetted into a 250 cc. volumetric flask and made up to mark with distilled water. This diluted juice sample was filtered with suction through a Buckner funnel containing a coarse filter paper covered with a hardened asbestos pad. All suspended matter was thereby removed and the juice came through sparkling clear. The volumetric flask was then rinsed thoroughly with distilled water, and the filtered juice sample replaced in the flask and held at 32° F. until ready for use. (If the juice sample is to be held for more than one day at 32° F. it should be brought to a boil to stop enzyme action, since considerable protopectin hydrolysis takes place upon standing.)

To displace water or juice retained from a previous sample in the asbestos pad, a flushing sample of 40 cc. of juice made up to 100 cc. with water, was run through the pad and the filtrate discarded. The filter pad was thus saturated with juice of the same dilution as the sample to be used. One coarse asbestos pad, one-quarter of an inch in thickness, will normally filter eight samples without excessive clogging, provided the surface of the pad is scraped now and then during filtration with a stirring rod.

The method of analysis used was that outlined by Carré and Haynes (9) with slight modification. Duplicate 100 cc. aliquots of the diluted juice were pipetted into 600 cc. beakers. To each beaker was then added 100 cc. of .10 normal sodium hydroxide and 200 cc. of water. The beakers were covered with watch glasses and the solution allowed to stand overnight in the laboratory to hydrolyze the methyl ester to the sodium salt of pectic acid.

In the morning 50 cc. of normal acetic acid were added to each beaker to decompose the sodium salt, and after 5 minutes, 50 cc. of molar calcium chloride were added to form the insoluble calcium pectate. The solution was then allowed to stand for an hour with occasional stirring, brought to the boil, filtered through coarse fluted filter paper, and the filtrate rejected.

The brown calcium pectate precipitate was then carefully washed five or six times with hot distilled water to remove the greater part of the chemicals adhering to it and was washed down first into a lump in the bottom of the filter paper and then into a beaker. From the beaker it was transferred into a tared Gooch crucible set in a rubber Gooch crucible holder in a side arm filtering flask, and the water removed from it as far as possible by suction. (Normally four samples can most expeditiously be run at one time, at the same time having the next four samples in process of preparation.)

The Gooch crucibles containing the calcium pectate were then dried for 48 hours to constant weight at 95° C., removed to a desiccator and reweighed. The difference in weight represented calcium pectate and varied from 1 to 60 milligrams. To obtain the actual amount of calcium pectate in 100 cc. of juice, the determination was multiplied by 6.25, the dilution factor. However, in presentation of results, the actual milligrams of calcium pectate obtained are given, which represent the amount in $\frac{100}{6.25}$ or 16 cc. of juice.

<u>Respiration determinations</u>. The apparatus used for this work consisted of a constant pressure vacuum line with connections to the different storage rooms, standard flow meters as described by Harding et al (25), and 4-gallon wide-mouth friction top cans with inlet and outlet connections, for enclosing the fruit. Air was drawn continuously through the cans containing about eight kilograms of fruit at a rate of 5 litres per hour. When a respiration determination was to be made the outgoing air from the can was by-passed through a Truog absorption tower containing 50 cc. .10 normal $Ba(OH)_2$ for a period of one-half hour to one hour. After the Truog

tower was disconnected, its contents (beads plus $Ba(OH)_2$... $BaCO_3$ solution) were washed into a beaker and titrated with .10 normal HCl. From the $Ba(OH)_2$ used up, respiration rate in cubic centimeters of CO_2 per kilogram of fruit per hour was calculated.

Acid determination. The method used for preparing a sample of tissue for acid analysis was as follows. A 100-gram composite sample of apple tissue taken from fifteen or more fruits was placed in a 600 cc. beaker and to it was added 300 cc. of distilled water. The water-tissue mixture was then covered with a watch glass, quickly raised to a temperature of 70° C. in a water bath, and held at this temperature with occasional stirring for 30 minutes. This procedure was found to give a satisfactory water extraction of the acid in the juice. The juice extract was cooled and 50 cc. aliquots titrated with .05 normal NaOH, using phenolphthalein as an indicator. The data on total acid are presented in terms of number of cc. of .05 normal NaOH required to titrate a 50 cc. aliquot of diluted juice. Active acidity (pH) was recorded with a Leeds and Northrup glass electrode pH recorder.

Qualitative starch determination of fresh fruit. Starch determinations with cut fruit were made by means of the well-known reaction between starch and iodine, the development of dark bluish black color in the presence of iodine indicating the presence of starch grains. The disappearance of starch in apple tissue through hydrolysis to glucose is a good gauge of the progress of the ripening process.

Six apples were cut across equatorially and the cut surfaces dipped in a tray containing a weak iodine solution (1 gram KI plus .25 gram I_2 made up to 100 cc. with water) for two minutes. They were then rinsed with cold water to remove excess iodine and dried with blotting paper. The quantity and distribution of starch could thus be ascertained and compared with a set of photographed standards. A series of photographs showing different stages in starch disappearance, as gauged by the iodine reaction, is shown in Figure 4. The iodine solution may be used a number of times if it is kept cool and in the dark.

<u>Preservation of apple tissue for subsequent determination of sugar, starch, and insoluble residue</u>. A sample of apple tissue consisted of a composite of equal parts from fifteen or more fruits. The apples were cut equatorially, cored, and millimeter slices made with a kraut cutter. Each slice was stacked on top of the other slices to prevent oxidation, and wedges were cut out of the stacked slices until the exact weight of the sample was reduced to 100 grams. The sample was then cut into smaller pieces and dropped into a screw-top quart sealer containing 400 cc. of boiling ethyl alcohol. One season 85 per cent denatured ethyl alcohol was

used (85 per cent ethyl plus 15 per cent methyl) which showed a very low reducing value and seemed as satisfactory as pure ethyl. The sample was simmered lightly for 15 minutes on top of the water bath, and then the top screwed on tightly and the jar removed to cool. The samples were held at 32° F. until the time they were analysed.

Extraction and analysis of the samples followed the procedures outlined by Loomis and Shull (39). The alcohol extract from the tissue was poured off through a coarse filter paper into a 2000 cc. volumetric flask and the tissue transferred to a 400 cc. beaker. Sufficient alcohol was poured over the tissue to cover it, and it was simmered on the water bath for 15 minutes, cooled and the alcohol poured off again into the 2000 cc. volumetric flask. After fifteen such extractions with each sample, the volumetric flask was filled up to the mark with alcohol, and the extracted residue dried at 95° C., weighed, and stored in moisture-proof bottles.

Sugar. From the alcohol extract 25 cc. aliquots were taken for analysis, the alcohol evaporated off, the solution cleared with neutral lead acetate, and made up to a volume of 250 cc. This was then deleaded by pouring it onto an excess of anhydrous sodium oxalate in a 500 cc. Erlenmeyer. From this deleaded sample, duplicate 50 cc. aliquots were taken for analysis to determine reducing sugars. To determine sucrose, 50 cc. aliquots were inverted overnight by use of 4 drops of fresh 1 per cent invertase solution. The difference in reducing sugars between the untreated and invertase-treated aliquots represented sucrose. Sucrose values were multiplied by .95 to correct for the molecule of water added upon hydrolysis of sucrose to simple sugar. Sugars in both instances were determined by the modified Munson-Walker-Bertrand method as described by Loomis and Shull (39).

Starch. Starch was determined from the dried. finely ground residue remaining after the alcoholic separation of soluble and insoluble materials. Samples of 0.5 grams were placed in 600 cc. Erlenmeyer flasks, covered with 100 cc. of water, and heated for 30 minutes in a boiling water bath to gelatinize the starch. The samples were cooled to about 35° C. and 3 cc. of fresh saliva added, and the samples allowed to stand overnight at 35° C. The solution was then filtered, leaded, made to a volume of 250 cc. and filtered onto 0.4 gm. of sodium oxalate to delead the solution. 200 cc. of the extract was autoclaved for 60 minutes at 15 pounds pressure with 10 cc. of concentrated HCl, and glucose determined on the neutralized extract, according to the method for reducing sugar.

For estimating with fair accuracy the amount of starch present in apple tissue, the following method was employed. The dry weight of the alcohol-leached residue from a sample of apples at picking, or at any stage in storage when starch was known to be present, was determined. From this value was subtracted the weight of the alcohol-leached residue from a sample of the same lot of apples after all starch was known to have disappeared, as judged by the iodine test. The remainder represented starch plus a very small amount (less than 0.2 per cent) of protopectin hydrolyzed over to the soluble pectin form.

C. Results

1. Environmental factors affecting fruit quality

It was recognized at the outset that one of the most important steps in a study of mealiness in Delicious was to make a survey of the Delicious crop grown in different orchards in different areas, to ascertain the influence of environmental factors and cultural methods upon the quality of the crop. This was done in the season of 1937 and again in 1939 in different districts of the Okanagan Valley of British Columbia. General observations for the 1940 season are included. The data will be presented in full for 1937 and summarized for 1939 and 1940.

1937. From four different orchards in each of the districts of Oliver, Penticton, Kelowna, and Vernon, two-box samples of fruit were obtained at time of picking. These were transported immediately to Summerland Experimental Station and placed unwrapped in 32° F. storage within 48 hours of time of picking.

At the time of collecting the samples, records were taken as to conditions under which the fruit was grown, age of trees, maturity of fruit, and other factors which might influence its quality. This information is set forth in Table 1. The fruit was picked in Oliver on October 7, in Penticton on October 8, in Kelowna on October 12, and Vernon on October 13.

Two removals of fruit were made from cold storage to the 60° F. ripening room, one on November 5 and the other on April 4. The behaviour of these apples after removal from cold storage is recorded in Tables 2 and 3.

In Table 2 is shown the maturity of the different lots of fruit at time of picking, their size, and degree of colour, in relation to firmness and keeping quality. The onset of overripeness was judged by development of mealiness and the "stale" flavor characteristic of Delicious apples past their prime.

The data set forth indicate a rather wide variation in firmness at time of picking, showing little correlation with district, with maturity, or with soil. On the whole, however, the Delicious from the Oliver and Kelowna districts were softer than those from Vernon and Penticton. Firmness

Table 1. Description of orchards from which fruit was taken for storage.

Oliver District	Grower			
	A. Gilman	J.W. Neil	H. Earle	J.B.MacNaughton
Soil type	Sandy loam	Gravelly loam	Heavy sand loam	Gravelly loam
Irrigations	3	4 or 5	5	7 or 8
Age of trees	14 years	11 years	15 years	15 years
Size of crop	Moderate	Heavy	Heavy	Heavy
Cover crop	Moderate alfalfa	Good alfalfa	Good alfalfa	Sweet clover & alfalfa
Slope of land	Slight	Heavy	Slight	Slight
Penticton District	H.Barnard	R.Penrose	H. Munson	Capt.Robinson
Soil type	Gravelly loam, underlaid with black loam	Clay loam	Heavy clay	Gravelly loam
Irrigations	4	2 or 3	4	4
Age of trees	30 years	24 years	30 years	12 years
Size of crop	Heavy	Heavy	Heavy	Medium
Cover crop	Miscel-laneous	Alternate years	Miscel-laneous	Miscellaneous poor
Slope of land	Moderate	Moderate	Slight	Flat

Table 1, continued.

Kelowna District	Grower			
	J. S. Sterling	McTavish & Fitzgerald	R. Seath	A. McKay
Location	South Kelowna	East Kelowna	Glenmore	Glenmore
Soil type	Deepclay	Shallow sandy loam	Deep silt	Deep clay
Irrigations	4	4	5 or 6	5 or 6
Age of trees	26 years	22 years, grafted 12 yrs.ago	26 years	25 years
Size of crop	Heavy	Medium	Heavy	Heavy
Cover crop	Miscel-laneous	Miscel-laneous	Miscel-laneous	Very little
Slope of land	Slight	Slight	Moderate	Moderate
Vernon District	Watson Estate	Bates Orchard	Vernon Orchards	J. Webster
Location	East Vernon	East Vernon	North Vernon	Coldstream
Soil type	Deep gra-velly loam	light loam, hardpan at 2 in.	Heavy deep clay	Black sandy loam, fairly deep
Irrigations	3	3	3	3
Age of trees	25 years	12 years	25 years	25 years, grafted 5 yrs.ago
Size of crop	Heavy	Heavy	Heavy	Moderate
Cover crop	Miscel-laneous	Little, mis-cellaneous	Little, mis-cellaneous	Weeds
Slope of land	Slight	Moderate	Moderate	Slight

Table 2. Effect of district, soil, and cultural methods on storage life of Delicious. (Fruit removed from 32°F. storage to 60°F., November 5, 1937.)

District and grower	Color	Size	Maturity	Firmness when picked	Firmness 2 weeks after removal to 60°F.	Flavor in prime condition	Observations after 3 weeks			days to become overripe at 60°F.
							Scald	Mealiness	Flavor	
				lb.	lb.			*		
Vernon										
Watson Estate	Fairly good	Medium to large	Good	19.8	14.0	Fair	0	M	Fair	14
E.S.Bates	Good	Large	Good	19.9	13.9	Good	0	E	Fair	21
Vernon Orch.	Fair	Medium	Fair	18.5	13.1	Fair	0	E	Stale	14
J.Webster	Good	Small	Poor	18.9	15.0	Fair	0	0	Fair	28
Kelowna										
J.S.Sterling	Fair	Medium	Poor	16.7	13.1	Poor	0	E	Poor	/
McTavish	Good	Large	Good	17.3	12.6	Good	0	E	Fair	14
R. Seath	Fair	Medium	Fair	18.6	12.5	Poor	0	0	Poor	/
A. McKay	Fair	Medium	Fair	18.4	12.7	Fair	0	E	Stale	16
Penticton										
H. Barnard	Good	Medium	Good	16.8	13.3	Fair	0	0	Fair	21
R. Penrose	Fair	Medium	Good	18.6	12.0	Fair	0	E	Fair	14
H. Munson	Fair	Medium	Poor	18.1	14.9	Fair	0	0	Poor	21
Capt. Robinson	Poor	Small	Poor	18.9	14.0	Poor	0	0	Stale	/
Oliver										
A. Gilman	Poor	Medium	Poor	17.0	11.8	Poor	0	0	Stale	/
J.W. Neil	Good	Large	Good	16.7	13.0	Fair	0	0	Fair	21
H. Earle	Good	Medium	Fair	17.2	12.8	Fair	0	0	Fair	21
J.B.MacNaughton	Fair	Medium	Good	15.9	12.1	Fair	0	E	Stale	14

* M - Medium, E - Excessive, 0 - None

/ Apples never attained desirable flavor.

was not always correlated with maturity since the firmest apples (those obtained from the Watson and Bates orchards in Vernon) were fully mature when picked.

On November 19, two weeks after removal from cold storage, there was not such a marked variation in firmness of the different lots of fruit, although the fruit from Vernon was still the firmest, and that from Oliver and Kelowna still the softest.

The flavor of all lots of fruit included in this test was subnormal for the Delicious variety. In some cases poor flavor could be ascribed to immaturity at harvest time, but even fruit which gave every evidence of proper maturity when picked, lacked that piquant flavor and aroma which characterizes a first-class Delicious apple. This condition was apparently quite general in fruit of the Delicious variety during the 1937-38 season, and can probably be attributed to seasonal weather conditions.

After ripening, the different lots of fruit showed a distinct correlation between maturity when harvested, flavor and development of mealiness. In no case did fruit that was immature when picked attain good flavor. Several lots of immature apples seemed low in sweetness, and insipid and unpleasant to the taste throughout the entire storage period. The development of mealiness, and the time at which it appeared, were positively correlated with maturity, the more mature the apples the greater was the amount of mealiness and the faster it developed. No mealiness was noted in immature Delicious throughout the period they were under observation. The period for each lot of apples to become overripe at 60° F. was noted and varied between 14 and 28 days.

The records covering fruit removed April 4 give a comparison of the different lots of fruit as they approached the end of their storage life. The information obtained is presented in Table 3.

The relative firmness of the apples on this removal was still the same as at time of picking, with the Vernon apples the firmest and the Oliver fruit the softest. Many of the samples had apparently passed their period of prime eating condition by April 4. They were insipid and had a disagreeable "off" flavor. Even the best samples possessed only fair flavor, and remained in eating condition between 4 and 9 days. As in fruit of the November removal, development of mealiness was usually correlated with maturity.

No scald was evident on any of the lots of Delicious at time of removal, but on April 13, after 9 days at 60° F., a considerable amount of scald had developed. The development of scald is usually associated with immaturity, but this correlation did not consistently hold with the Delicious involved in this experiment. There was practically no scald

Table 3. Effect of district, soil, and cultural methods on storage life of Delicious.
(Fruit removed from 32° F. storage to 60° F., April 4, 1938.)

District and grower	Color	Size	Maturity	Firmness when picked	Firmness 2 weeks after removal to 60°F.	Flavor in prime condition	Observations after 9 days			Days to become overripe at 60° F.
							Scald	Mealiness	Flavor	
				lb.	lb.		%	*		
Vernon										
Watson Estate	Poor	Medium to large	Good	19.8	13.7	Fair	22	0	Fair	9
E.S.Bates	Good	Large	Good	19.9	13.8	Fair	17	0	Fair	9
Vernon Orch.	Fair	Medium	Fair	18.5	13.1	Fair	27	0	Poor	4
J. Webster	Good	Small	Poor	18.9	14.3	Poor	40	0	Poor	⌿
Kelowna										
J.S.Sterling	Fair	Medium	Poor	16.7	12.1	Poor	0	M	Poor	⌿
McTavish	Good	Large	Good	17.3	12.0	Fair	2	E	Stale	5
R. Seath	Fair	Medium	Fair	18.6	13.4	Fair	3	0	Poor	⌿
McKay	Fair	Medium	Fair	14.4	12.8	Fair	0	M	Fair	7
Penticton										
H. Barnard	Good	Medium	Good	16.8	17.6	Fair	0	E	Fair	5
R. Penrose	Fair	Medium	Good	18.6	12.1	Fair	16	E	Poor	5
H. Munson	Fair	Medium	Poor	18.1	14.1	Poor	19	0	Poor	⌿
Capt. Robinson	Poor	Small	Poor	18.9	12.2	Poor	3	0	Poor	⌿
Oliver										
A. Gilman	Poor	Medium	Poor	17.0	13.6	Poor	17	0	Poor	⌿
J.W. Neil	Good	Large	Good	16.7	11.1	Fair	4	M	Fair	6
H. Earle	Good	Medium	Fair	17.2	12.4	Poor	36	0	Poor	⌿
J.B. MacNaughton	Fair	Medium	Good	15.9	11.9	Fair	2	0	Poor	9

* M - Medium, E - Excessive, 0 - None

⌿ Apples ripened but never attained desirable flavor.

on the Kelowna fruit, although maturity on the whole was under the optimum, while on the Vernon fruit, which was more mature when picked, a considerable amount of scald developed. In the Penticton fruit, one lot showing good maturity developed scald, while the least mature lot of fruit was practically scald-free. In the Oliver fruit there was a positive correlation between scald development and immaturity. On the whole the tendency was for the less mature fruit to show more scald, but factors other than maturity seem to have influenced amount of scald in the fruit used in this experiment.

1939. In 1939 the season was cool and rather late with the result that maturity of Delicious at picking was on the whole rather inadequate. The fruit was often of fair color, but showed a somewhat greenish flesh color, and lacked the characteristic flavor of the variety. Instead it was rather insipid. It was characteristic of almost all Delicious examined during that season that development of mealiness was rather slight, and in many lots, the fruit really never became mealy. However, the fruit acquired after removal from storage a particularly stale objectionable flavor.

From the standpoint of quality and flavor in the Delicious variety, 1939 was on the whole rather a poor season. From the standpoint of development of mealiness in the fruit it was a good season. The results of the 1939 season seemed to indicate that the subnormal maturity of the fruit and relatively slight occurrence of mealiness were rather closely associated.

1940. The 1940 season was warm and dry during the summer and remained so well on into the fall. Maturity of Delicious at picking was excellent and quality unusually fine. 1940 could justifiably be called a "vintage year" for this variety. However, it was noted rather generally that the fruit did tend to go mealy; in fact, fruit held in common storage at 60° F. for three weeks was decidedly mealy. Late in the storage season (March 1) commercial samples examined in 32° F. storage showed definite signs of mealiness. The 1940 season was thus good for developing fruit of high quality, but poor because the fruit had a strong tendency to go mealy.

In this connection it is interesting to correlate "heat units" during the growing season with maturity and storage quality of the fruit. Heat units have been calculated in 10-day periods from May 10 to September 30 for the seasons 1939, 1940, and 1941. For this purpose, the temperature each hour of the day was taken from the Station thermographic records. In calculating heat units for each 10-day period, a 50° F. base was used, and the number of hour-degrees in excess of 50° F. were totalled. These data are presented graphically in Figure 3.

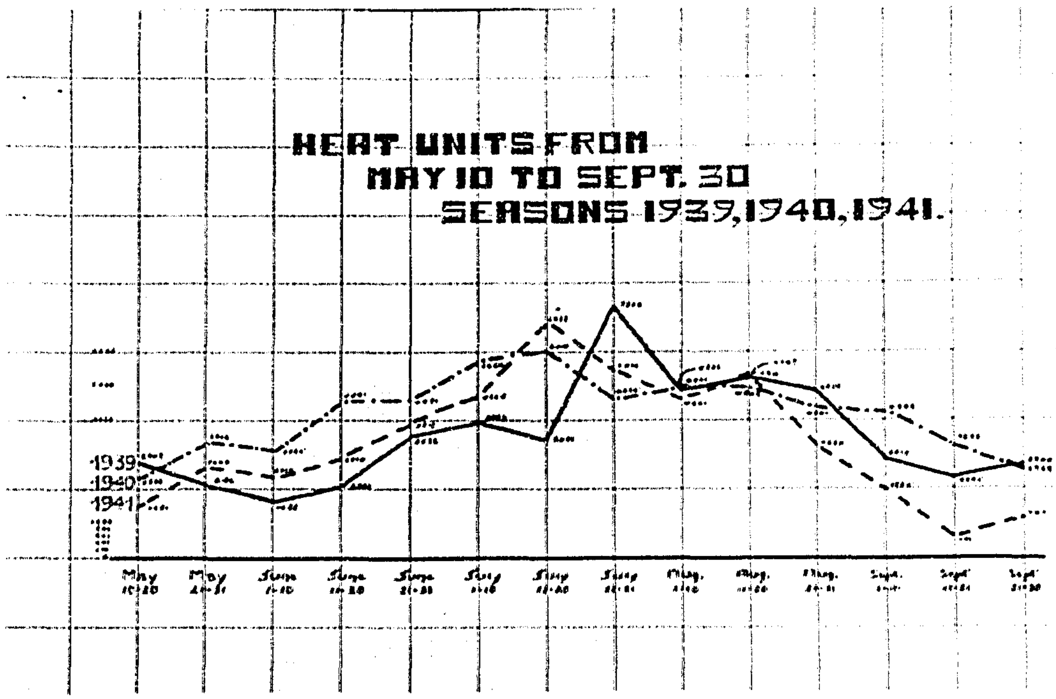


Figure 3. Heat units for 10-day periods from May 10 to September 30 for seasons 1939, 1940, and 1941. See text for correlation between heat units and maturity and quality with Delicious apples.

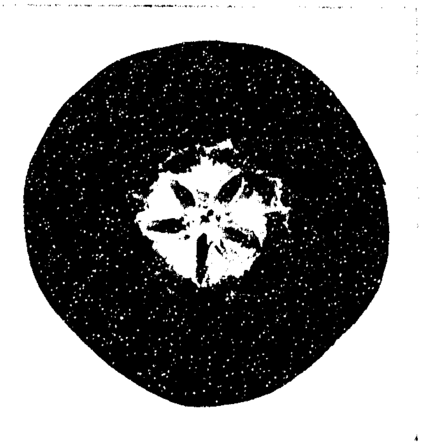
It will be noted that in 1940 when maturity and quality of Delicious were excellent, the season was unusually warm from start to finish. On the other hand, in 1939, when maturity and quality were deficient in this variety, the season was unusually cool until mid-July, and after that of only moderate warmness. This season (1941), Delicious tend to be of inferior quality, which is not surprising since early season temperatures were only moderately warm, while from the middle of August to the end of September, they were particularly cool. It is apparent that there is a strong correlation between growing season temperatures, maturity, quality, and susceptibility to mealiness in Delicious apples.

These general observations on seasonal and orchard variation in the Delicious variety seem important because they show that the problem of quality is not only a matter of development of mealiness in the fruit, but also that poor insipid flavor is often equally responsible for poor quality. Quality of the fruit varied greatly in apples from different orchards, and was markedly influenced by the season. Fruit in an immature condition, such as that from overloaded, poorly thinned trees, or fruit picked too early, practically never became mealy. Large sized apples of good maturity were of highest quality, but seemed most susceptible to mealiness. Investigational studies relating to improvement in quality of Delicious apples must take these important factors into consideration.

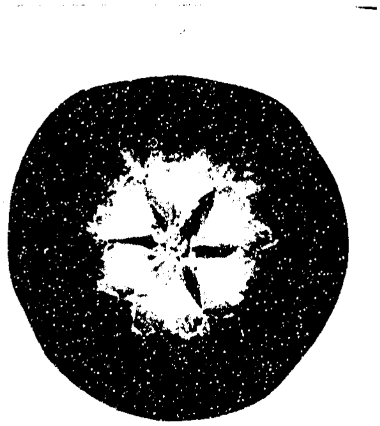
2. Harvesting maturity in relation to fruit quality

In the fall of 1939 a systematic study of date of harvest in relation to quality in Delicious was carried out. For this experiment fruit from three mature full-bearing trees was harvested at five successive weekly intervals starting September 26 and extending through to October 24. The fruit from each of the three trees was handled separately, wrapped in plain and oiled wraps and placed immediately in 32° F. storage. At the time each lot was picked, an iodine test was made for starch, acid determinations were carried out, and representative 100-gram samples of tissue preserved in 80 per cent ethyl alcohol for future analysis. On February 12, the fruit was removed from cold storage for examination, and examined again three weeks later after holding at 60° F. On both dates, acidity and pectin determinations were made and samples of tissue preserved in alcohol for analysis. On May 6 a further removal of fruit from cold storage was made.

Starch-iodine test. At each date of picking, an iodine test for starch disappearance was made, and the resulting reaction matched against the set of eight standards presented in Figure 4. The change in the starch-iodine picture from week to week is presented by number in Table 4. Included also in this table is the percentage of starch in



Stage 1



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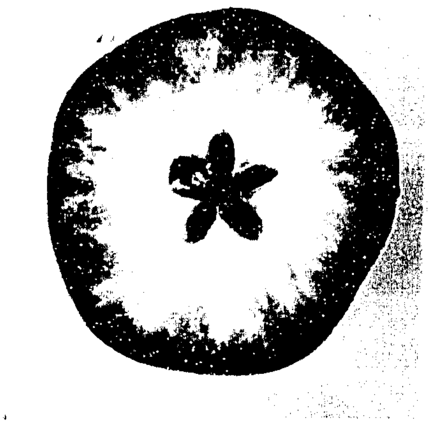

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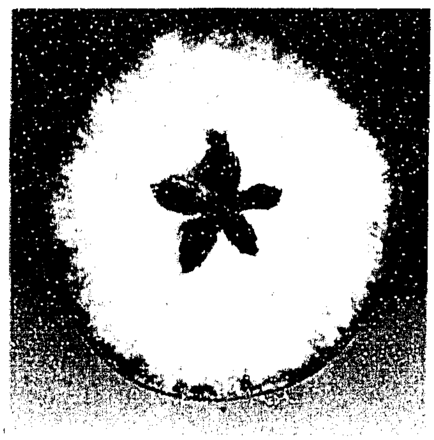
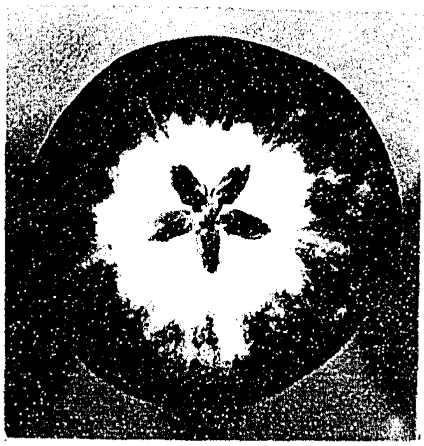
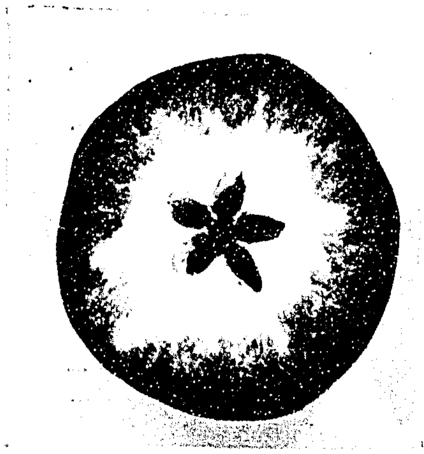


Stage 6

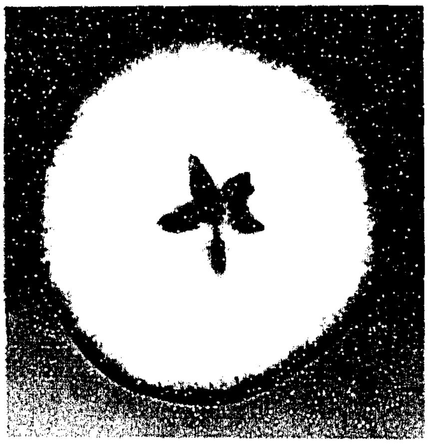
Figure 4. Progressive stages in starch hydrolysis
as indicated by the starch-iodine



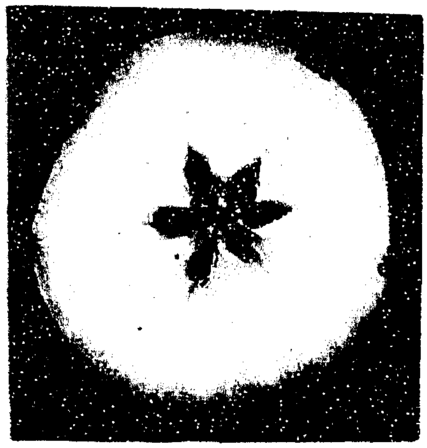
Stage 3



Stage 4



Stage 7



Stage 8

es in starch hydrolysis of Delicious apples
ed by the starch-iodine test.

the fruit as determined by differences in weight of alcohol-insoluble tissue residue at picking and after storage.

Table 4. Effect of date of harvest upon amount of starch present in fruit at time of picking as judged by the iodine test, and by differences in weight of alcohol-insoluble tissue residue at picking and after approximately four and one-half months' storage at 32° F.

Date of harvest	Stage of starch-iodine reaction at picking	Dry weight of alcohol-insoluble residue		Estimated starch by difference at time of picking
		At harvest	After storage (Feb.15)	
		%	%	%
Sept.26	1	4.10	2.11	1.99
Oct. 3	1-2	4.01	2.01	2.00
Oct. 10	2	4.00	2.00	2.00
Oct. 17	2	4.05	1.97	2.08
Oct. 24	3	3.01	1.96	1.05

From these data it is apparent that there was a gradual change in starch content from the earliest picking, September 26, until the last picking on October 24. On the three intermediate dates of harvest there was scarcely any perceptible change in the starch picture. Between October 17 and 24, however, there was a sharp drop in the starch content picture which moved from Stage 2 to Stage 3. It is interesting to note that of the five pickings, the fruit harvested on October 24 was the only fruit which developed really high quality. (The general date of harvest for Delicious in this season was October 5 to 15.) These data indicate, and further observations have substantiated, that for reasonably good quality in Delicious, the starch must practically have cleared from within the coreline, and there must be small radiating patches where it is disappearing beyond the coreline. Certainly fruit picked while there is still a heavy deposition of starch within the coreline will be of low quality.

The actual differences in weight of dried alcohol-insoluble residue between samples taken at different dates of picking and after removal from cold storage indicate starch values closely paralleling those shown by the starch-iodine reaction. There was a rather small reduction of starch until the week from October 17 to October 24, when starch dropped from 2.08 per cent to 1.05 per cent.

<u>Quality of fruit when removed from storage</u>. When removed from cold storage to the 60° F. ripening room on February 15, and when examined three weeks later, pressure tests, quality, and scald ratings were made. These data are set forth in Table 5.

It had been hoped in this experiment that some marked differences would be noted in development of mealiness in relation to date of harvest. However, in the 1939 season, as previously noted, Delicious were slow to mature, and very few lots examined that season showed any pronounced inclination to become mealy. None of the fruit used in this experiment became mealy even after three weeks' storage at 60° F. When held at 60° F. for a period of five weeks, at which time the apples were overripe, only slight mealiness developed in some samples.

Table 5. Effect of date of harvest upon keeping quality of Delicious apples removed from cold storage, February 12, 1940.

Tree No.	Date of harvest	Condition of fruit					
		On removal to 60°F.			After 3 weeks at 60° F.		
		Firmness	Scald	Flavor	Firmness	Scald	Flavor
		lb.	%		lb.	%	
310	Sept.26	14.1	0	poor	11.9	0	poor, stale
312	"	13.1	5	"	12.1	3	" "
313	"	12.8	0	"	11.8	2	" "
310	Oct. 3	13.7	0	poor	11.1	0	poor, stale
312	"	12.7	0	"	11.7	0	" "
313	"	12.4	0	"	11.1	0	" "
310	Oct. 10	13.6	0	poor	11.4	0	poor, stale
312	"	13.2	0	"	11.5	0	" "
313	"	12.1	0	fair	11.2	0	" "
310	Oct. 17	13.1	0	good	11.6	0	fair, stale
312	"	12.9	0	fair	----	0	" "
313	"	12.7	0	"	11.2	0	" "
310	Oct. 24	14.0	0	good	11.3	0	fair
312	"	12.7	0	"	11.3	0	fair, stale
313	"	11.8	0	"	11.0	0	fair

N.B. Since none of the lots became mealy, no heading for mealiness is given.

Flavor. Flavor in Delicious apples is not easy to describe. The characteristic flavor of this variety seems to be dependent upon certain delicate esters which seem to disappear when the fruit is held too long or reaches the stage of overripeness. If the fruit is picked immature, these flavoring constituents do not appear to develop to the same extent as in mature fruit, and varietal flavor is correspondingly reduced. When overripe all Delicious apples acquire a stale aldehydic flavor. Those picked immature seem to acquire this flavor most strongly, and are particularly disagreeable to the taste.

At the time the various lots of apples were removed from cold storage there was no stale flavor evident in any of the samples, although characteristic varietal flavor was lacking in fruit picked on the first three dates. Fruit picked on October 17 or 24 was fair or good in flavor. After being held for three weeks at 60° F. most fruit of the first three pickings was poor in flavor with a disagreeable musty taste. The fruit of the last two pickings was fair or poor in flavor, but only part of the samples had taken on the stale flavor of overripe Delicious.

Firmness. From this tabulation it is apparent that firmness of Delicious was not significantly affected by date of harvest. At time of removal the different lots averaged about 13.0 to 13.5 pounds in hardness, and after three weeks at 60° F. this had dropped to about 11.0 to 11.5 pounds.

Scald. Practically no scald was evident on any of the fruit. Trees number 312 and 313 showed very slight scald and this only with earliest picked samples. Taking apples of all varieties as a whole, scald was practically non-existent in cold stored fruit of the 1939 crop.

<u>May 6 removal</u>. Samples of oil-wrapped fruit similar to the samples removed on February 12 were held in 32° F. storage until May 6 when they were removed to the 60° F. ripening room. The apples were purposely held until this late date to ascertain whether late holding would bring out differences in storage capacity of the different lots not detectable in earlier removals. The fruits were examined after two weeks' storage at 60° F. and notes made as to firmness, mealiness, flavor, and scald. Results are given in Table 6.

Table 6. Effect of date of harvest upon storage quality of Delicious removed from 32o to 60oF. on May 6, 1940.

Tree no.	Date of harvest	Firmness	Mealiness	Scald	Flavor
	1939	lb.		%	
310	Sept.26	11.6	Very slight	6	Poor
312	"	11.2	Slight	0	Poor, slightly stale
313	"	11.5	Very slight	0	Poor, very stale
310	Oct. 3	11.1	Very slight	4	Poor
312	"	11.0	Slight	0	Poor
313	"	10.8	Very slight	0	Poor, very stale
310	Oct. 10	11.5	Slight	0	Poor
312	"	11.3	Slight	0	Poor
313	"	10.9	Very slight	0	Poor, slightly stale
310	Oct. 17	11.7	Slight	0	Fair
312	"	10.9	Slight	0	Poor
313	"	11.0	Slight	0	Fair, slightly stale

From this table it is evident that cold storage of Delicious until May 6 induced either a very slight or slight degree of mealiness in all lots. Firmness was similar in all samples and did not seem to be influenced by maturity at picking. Scald was noted with only one tree on the first two picking dates. Flavor was poor in fruit of the first three pickings, and fair in two trees out of three on the last picking. There was also some variation in the development of stale flavor in the different lots. The earliest picked apples, if anything, were the most stale and disagreeable in flavor.

Date of harvest and chemical composition of Delicious. Chemical analyses to determine influence of date of harvest on acidity, soluble pectin values, and sugar content of Delicious apples harvested on the five dates of picking are given in Tables 7 and 8.

Table 7. Effect of date of harvest upon total acidity, pH, and soluble pectin content of Delicious apples.

Date of harvest	At picking		On removal from cold storage, Feb.15			After three weeks at 60° F.		
	Acidity		Acidity		Soluble pectin /	Acidity		Soluble pectin /
	pH	Total *	pH	Total *		pH	Total *	
1939		cc.		cc.	mg.		cc.	mg.
Sept.26	4.28	7.10	4.41	6.55	11.2	4.61	6.20	21.3
Oct. 3	4.26	7.15	4.51	6.60	14.6	4.64	5.70	20.7
Oct. 10	4.30	7.15	4.52	6.20	15.5	4.70	6.30	24.3
Oct. 17	4.33	7.20	4.64	5.85	13.2	4.77	5.10	20.3
Oct. 24	4.26	7.40	4.67	5.85	10.5	4.76	5.60	18.6

* expressed as .05 N. NaOH to titrate 12.5 cc. juice.
/ expressed as calcium pectate per 16 cc. juice.

In Table 7, a progressive reduction in total acid content is indicated from time of picking until after removal from storage. While there did not seem to be much difference in acidity of the different pickings at time of harvest, after removal from cold storage the later picked apples showed a lower total acid content. pH values likewise increased as the storage period progressed, the changes closely paralleling decreases in total acid content.

Pectin content of Delicious in terms of calcium pectate varied somewhat from picking to picking, increasing from around 13 mg. to 21 mg. per 16 cc. juice from the time the fruit was removed from storage until three weeks later. There did not seem to be any significant differences in pectin values associated with date of harvest, a fact borne out by the finding that none of the lots showed any differences with regard to firmness or mealiness.

The influence of date of harvest upon sugar content of the fruit is indicated in Table 8.

Table 8. Effect of date of harvest upon sugar content of Delicious apples at picking and after four and one-half months' storage at 32° F.

Date of harvest	Sugar content on fresh weight basis					
	At picking			After storage		
	Reducing	Sucrose	Total	Reducing	Sucrose	Total
	%	%	%	%	%	%
Sept. 26	7.48	1.32	8.80	9.11	1.24	10.35
Oct. 3	7.46	1.50	8.96	8.99	1.32	10.31
Oct. 10	7.20	1.71	8.91	9.24	1.18	10.42
Oct. 17	7.12	1.70	8.82	8.99	1.52	10.51
Oct. 24	6.81	2.17	8.97	8.85	1.75	10.60

These data indicate rather small differences in sugar content of the fruit from different picks. It was interesting, however, to note that there was a tendency for sucrose content to increase and reducing sugars to decrease slightly with advancing maturity. The increase in sugar content between picking and removal of fruit from cold storage is accounted for by the hydrolysis of starch to reducing sugar. After storage for four and one-half months at 32° F., the percentage of sucrose had declined consistently.

3. Effect of temperature of storage upon rate of ripening and development of mealiness.

The period in the storage life of a Delicious apple at which mealiness develops is governed to a large degree by speed of ripening which in turn is governed by temperature of storage. In a study of this kind, therefore, it was necessary to make a rather thorough study of the influence of storage temperature upon rate of ripening and the chemical changes occurring in the fruit.

(a) Rate of ripening at different temperatures. In the 1939-40 and the 1940-41 seasons, Delicious of optimum maturity were held at 60°, 40°, and 32° F. from time of picking. The fruit was sampled at intervals to determine when it had become eating ripe and overripe. The data are presented in Table 9. On the basis of time required to reach certain stages of ripeness, these data indicate that Delicious ripen about three times as fast at 60° F. as at 40° F., and about 1.6 times as fast at 40° F. as at 32° F. Delicious were overripe in five to six weeks from picking when held at 60° F.; in fifteen to sixteen weeks when held at 40° F.; and in twenty-four to twenty-seven weeks when held at 32° F.

Table 9. Effect of storage temperature on rate of ripening in Delicious measured by condition at various periods in storage.

Degree of ripeness	Rate of ripening from time of picking		
	60° F.	40° F.	32° F.
	weeks	weeks	weeks
1939-40			
Eating ripe	2	7	12
Overripe	5	16	27
1940-41			
Eating ripe	2	6	9
Overripe	6	15	24

(b) Delayed storage and keeping quality of Delicious. Delicious apples were picked from two trees (numbers 653 and 654) in the Station orchard on October 14, 1938, at optimum maturity. Sufficient apples were picked to pack twenty boxes from each tree. Four boxes of each lot were packed and cold stored immediately at 32° F. and four from each lot at 40° F. After one, two, and three weeks' delay, respectively, four boxes from each lot were packed and stored at 32° F. The delayed fruit was held loose in boxes on the floor of the packing house at a temperature of about 60° F. The firmness of the apples was determined by the use of a standard Ballauf pressure tester just before placing the fruit in cold storage. These data are found in Table 10.

Table 10. Effect of delayed storage upon softening of Delicious prior to cold storage (fruit picked October 15).

Tree no.	Date of storage	Firmness
		lb.
653	Oct. 15	18.2
	" 22	17.7
	" 29	14.9
	Nov. 5	12.2
654	Oct. 15	18.1
	" 22	18.1
	" 29	15.7
	Nov. 5	13.1

During the delayed storage period at 60° F., Delicious softened as much as 5 and 6 pounds in pressure in three weeks. Softening during the first week was rather slight, but during the last two weeks softening was rapid. These data indicate the importance of immediate cold storage for this variety.

One set of ten boxes was removed from cold storage to the ripening room (temperature 65° F., relative humidity 85) on January 4, and similar sets removed subsequently on February 7, March 6, and April 3.

The first examination in each case was made on the day after removal from cold storage. The firmness of the fruit was determined at each examination and a total of

20 apples were examined each time. The fruit was held in the ripening room for two weeks, being examined at weekly intervals. The data obtained are presented in Tables 11, 12, 13, and 14.

Pressure tests. If ripening in apples following harvest is accurately gauged by pressure test, the data show that Delicious softened as much in three weeks on the packing house floor as in three months in cold storage at 32° F. At 40° F. Delicious softened as much in three months as apples stored at 32° F. for six months. These differences in pressure tests did not tend to level out during storage, as the initial variations were maintained.

At about 11 to 12 pounds pressure the eating quality was at its best. Delayed storage of two and three weeks resulted in a rapid decline in quality. Fruit removed later than February did not appear to have softened much further during storage.

Quality and flavor. There is a great variation in quality and flavor of the Delicious apple which makes these points difficult to evaluate. In comparing flavor of different samples individual people may not agree and the same person may react differently to the same flavor at different times or according to the number of samples tasted. Disagreeable or "off" flavors that sometimes develop in storage apples are, however, rather quickly detected.

Table 11. Effect of delayed storage on condition of Delicious apples removed from 32° F. storage in January 1939.

Tree no. and date picked	Delay	Pressure at time of storage	January 4			January 11			January 18		
			Pressure	Quality	Mealiness	Pressure	Quality	Mealiness	Pressure	Quality	Mealiness
1938	weeks	lb.	lb.			lb.			lb.		
32° F.											
653 Oct.15	0	18.2	13.4	G	none	10.4	G	none	10.2	F	S
	1	17.7	12.9	G	none	9.9	G	none	9.7	P	S
	2	14.9	11.6	VG	S	8.7	F	S	8.9	P	S
	3	12.2	10.6	F	S	8.6	P	S	9.3	P	S
654 Oct.15	0	18.1	13.3	G	none	11.1	G	none	10.1	G	none
	1	18.1	12.5	F-G	none	10.4	G	none	9.8	P	none
	2	15.7	11.8	F-G	none	9.9	F	none	9.1	P	none
	3	13.1	9.2	P	M	8.6	P	M	8.4	P	M
40° F.											
653 Oct.15	0	18.2	8.8	F-P	S-M	9.0	F-P	M	9.1	F-P	M
654 Oct.15	0	18.1	9.9	F-G	S	9.0	F	M	9.2	P	M

VG - very good; G - good; F - fair; P - poor; S - slight; M - moderate

Table 12. Effect of delayed storage on condition of Delicious apples removed from 32° F. storage in February 1939.

Tree no. and date picked	Delay	Pressure at time of storage	February 7			February 17			February 24		
			Pressure	Quality	Mealiness	Pressure	Quality	Mealiness	Pressure	Quality	Mealiness
1938	weeks	lb.	lb.			lb.			lb.		
<u>32° F.</u>											
653											
Oct.15	0	18.2	11.6	G-F	none	10.3	G-F	none	12.0	P	none
	1	17.7	11.2	G	none	9.6	F	VS	11.8	P	M
	2	14.9	10.3	F	S	8.9	P	S	10.5	P	M-E
	3	12.2	9.0	F	S	8.3	F-P O	S-M	7.5	P O	M-E
654											
Oct.15	0	18.1	11.3	G	none	9.4	G	---	10.8	F-P	S
	1	18.1	11.1	G	none	9.4	G-F	VS	11.5	F-P	S-M
	2	15.7	10.9	G	VS	9.1	F-P O	S-M	10.9	P O	M
	3	13.1	9.0	F	S	8.5	F	S-M	9.8	P	M-E
<u>40° F.</u>											
653											
Oct.15	0	18.2	9.6	G	VS	9.6	F	S	11.1	P	M
654											
Oct.15	0	18.1	9.3	G	VS	9.2	F	S	10.2	P	M

G - good; F - fair; P - poor; O - overripe; VS - very slight; S - slight; M - moderate; E - excessive.

Table 13. Effect of delayed storage on condition of Delicious apples removed from 32° F. storage in March 1939.

Tree no. and date picked	Delay	Pressure at time of storage	March 6			March 10			March 17		
			Pressure	Quality	Mealiness	Pressure	Quality	Mealiness	Pressure	Quality	Mealiness
1938	weeks	lb.	lb.			lb.			lb.		
32° F.											
653											
Oct.15	0	18.2	10.2	G	none	11.0	G	none	10.0	F O	VS
	1	17.7	10.6	G	none	10.2	G	VS	9.4	F-P	M
	2	14.9	9.8	F	none	9.3	F	S	8.7	P O	M-E
	3	12.2	9.6	F	S	9.1	F-P	S-M	8.7	P	M
654											
Oct.15	0	18.1	10.6	G	none	11.3	G	none	9.6	F	S
	1	18.1	10.2	G	none	10.6	F O	none	9.4	F-P	S
	2	15.7	9.1	F	none	9.5	F O	S-M	9.2	P O	M-E
	3	13.1	9.7	F	S	10.1	F-P O	S-M	8.5	P O	M
40° F.											
653											
Oct.15	0	18.2	9.6	F	VS	9.0	F O	VS	9.0	P O	S-M
654											
Oct.15	0	18.1	9.4	F	none	9.5	F	S-M	8.8	P	M

G - good; F - fair; P - poor; O - overripe; VS - very slight; S - slight;
M - moderate; E - excessive

Table 14. Effect of delayed storage on condition of Delicious apples removed from 32° F. storage in April 1939.

Tree no. and date picked	Delay	Pressure at time of storage	April 3			April 11		
			Pressure	Quality	Mealiness	Pressure	Quality	Mealiness
1938	weeks	lb.	lb.			lb.		
<u>32° F.</u>								
653 Oct.15	0	18.2	10.7	F-G	VS	10.0	F-P	S-M
	1	17.7	10.9	F-G	VS	soft	F-P	S-M
	2	14.9	10.3	F	S	overripe	0	E
	3	12.2	8.8	F-P	M	"	0	E
654 Oct.15	0	18.1	11.0	F-G	none	10.2	F-G	S
	1	18.1	11.5	G	none	soft	P 0	S-M
	2	15;7	10.0	F	S	overripe	P 0	M-E
	3	13.1	9.6	P	S	"	P 0	M
<u>40° F.</u>								
653 Oct.15	0	18.2	9.3	P	S-M	9.0	0	M
654 Oct.15	0	18.1	9.6	P	S-M	9.1	P 0	M

G - good; F - fair; P - poor; 0 - overripe; VS - very slight; S - slight; M - moderate; E - excessive

An attempt has been made to combine all of these conditions of texture, juiciness, flavor, etc., under the heading of quality, and to grade the results as: good, fair, poor, or over, or intermediate degrees as fair-good, etc. When quality was rated as poor it was generally due to stale flavor associated with the onset of mealiness. Lack of characteristic Delicious flavor was sometimes responsible for the quality being considered only fair.

It is of interest to note that best quality in Delicious was found in apples receiving immediate cold storage and those given the shortest delay. Fruit delayed two or three weeks in storage was of greatly reduced quality. Characteristic Delicious aroma was lacking in delayed storage apples when examined in March and April.

Delicious removed from cold storage later than February were of only fair quality, and remained in good condition only a little more than a week. Fruit given more than one week's delayed storage was definitely past its prime from February onwards. Fruit stored at 40° F. later than February was overripe upon removal from storage. It appears that immediate storage of Delicious at 32° F. is necessary to prolong the storage life of this variety until March. The quality of the fruit in this experiment declined rather quickly after removal from cold storage to the 65° F. ripening room. Best quality in Delicious cannot be maintained for more than one week at this temperature and this rapid decline becomes more pronounced as the cold storage period of the fruit is lengthened.

Mealiness. Mealiness spoils the dessert quality of the Delicious apple. Mealiness is associated with over-ripeness caused by long storage but it may occur very soon after harvest in apples held at high temperatures. Degree of mealiness was indicated as very slight, slight, slight to moderate, and excessive. The data indicate that mealiness was increased by (1) delayed storage, (2) length of storage, (3) length of time in ripening room after cold storage, and (4) storage at 40° F. rather than 32° F. Onset of mealiness and decline in quality were closely associated since a mealy Delicious apple usually takes on a stale aldehydic flavor.

(c) Respiration of Delicious at different temperatures. Respiration in fruits is an index of the biological activity of the tissue. Respiration rate increases as the temperature rises and has been found to be associated with changes in starch, sugars, acid, and pectin in ripening apples. Accordingly the trend and degree of respiratory activity in stored apples is of interest with reference to their storage capacity.

Respiration determinations were made with Delicious apples picked at four weekly intervals. Two lots were stored at 60° F.; two lots at 32° F. unwaxed; one lot at

32° F. waxed; and one lot stored at 40° F. These date have been represented graphically in Figures 5 and 6. Figure 5 depicts the respiration trend of Delicious stored immediately at 60° F., and Figure 6 the data for fruit stored at 32° F. and 40° F.

Figure 5 shows that a rapid increase in rate of respiration up to the climacteric took place in three out of the four pickings within about five days after harvest. The only exception to this statement was with the first lot of fruit, picked on September 26, in which case the climacteric rise was rather slower. Following the climacteric, the decline in respiration intensity was less rapid but continued long beyond the time the fruit was in prime eating condition. At the end of the decline following the climacteric, the fruit picked September 26 increased slightly in respiration intensity. All four lots of fruit were eating ripe two weeks after the date on which they were picked. At this time, respiration intensity was still high, but was on the gradual decline. The point at which the fruit began to lose flavor and become overripe is marked on the chart by heavy dots. Respiration determinations were continued well beyond the point at which the fruit became overripe to obtain a complete picture of the respiration trend.

In Figure 6 which represents the respiration trend of Delicious at 32° F. and 40° F., the absence of a

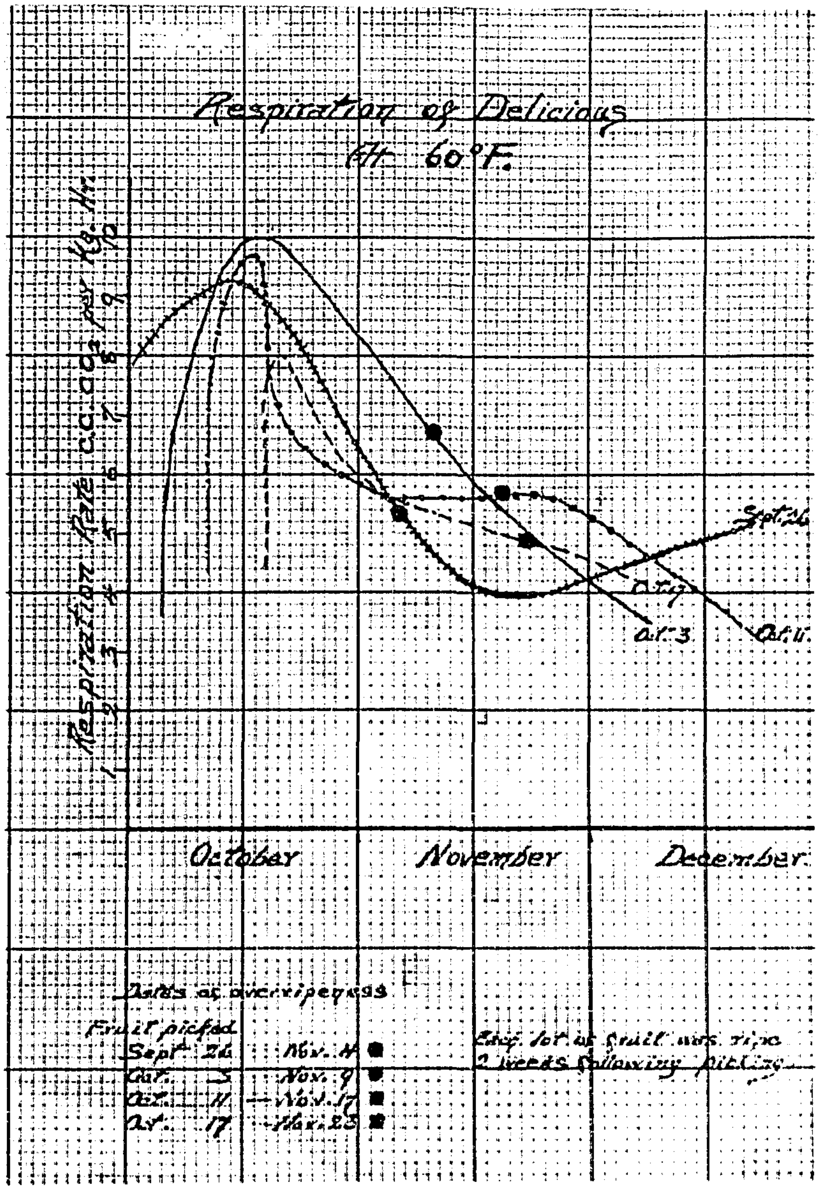


Figure 5. Respiration of Delicious harvested at weekly intervals and stored at 60° F. from time of picking. Respiration intensity expressed as cc. of carbon dioxide produced per kilogram of fruit per hour.

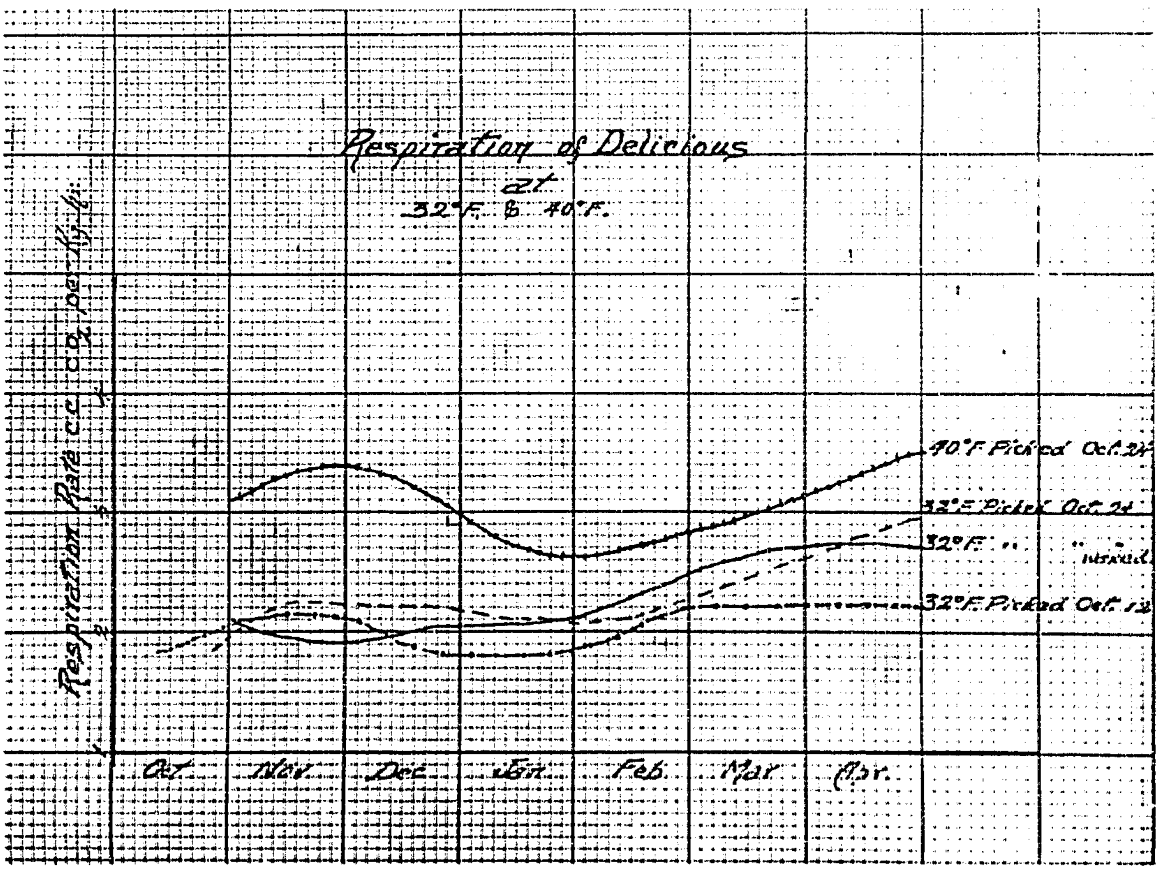


Figure 6. Respiration of Delicious apples held at 40° F. and 32° F. from time of picking. One lot of Delicious were waxed with a 5 per cent Brogdex wax emulsion. Respiration intensity expressed as cc. carbon dioxide produced per kilogram of fruit per hour.

marked climacteric rise is worthy of note. The fruit stored at 32° F. respired at a rate of about 2 cc. CO_2 per kilogram of fruit per hour, and the fruit stored at 40° F. at a rate of about 3 cc. CO_2 per kilogram of fruit per hour. The apples stored at 32° F. remained at about the same respiration level until the end of January at which time a considerable rise in respiration rate took place. At this time the fruit was eating ripe and had lost all its starch.

The respiration trend of the fruit stored at 40°F. was interesting. Following a slight rise from time of picking until the middle of December, there followed a decline in respiration until the middle of February, followed by a continuous rise from then on. This rise more or less paralleled a similar rise in the 32° F. stored fruit toward the end of the season, and probably was a reflection of changes leading to overripeness.

When speaking of the subject of respiration, it might prove of interest to discuss just what sugar losses are incurred through the respiratory process. For this discussion it will be necessary to assume a certain respiration rate and a certain storage life for Delicious at each temperature. These may be taken from data on storage life (page 59) at different temperatures and respiration rates given in Figures 5 and 6. It will be necessary to assume that respiration throughout the storage period is of the aerobic type; that is to say, the CO_2/O_2 ratio is 1, and also that loss of acid through respiration in Delicious apples is of a rather small amount, as indicated in Tables 19 and 27. For data let us take:

at 60° F., respiration rate of 6 cc. CO_2 per kg. hr., storage life 42 days;

at 40° F., respiration rate of 3 cc. CO_2 per kg. hr., storage life 105 days;

at 32° F., respiration rate of 2 cc. CO_2 per kg. hr., storage life 175 days.

The equation for respiration follows the schematic formula:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 677.2 \text{ calories}$$

$$180 \text{ gms.} + 192 \text{ gms.} \longrightarrow 264 \text{ gms.} + 108 \text{ gms.} \quad \text{(molecular weights)}$$

Taking the data for 60° F. storage:

In 42 days 1 kg. fruit respiring 6 cc. CO_2 per kg. hr. produces 42 x 24 x 6 = 6048 cc. CO_2.

1 gm. molecular weight of CO_2 (44 gms.) has a volume of 22400 cc.

6048 cc. CO_2 thus weighs $\frac{6048}{22400} \times 44 = 11.9$ gms.

From the equation, 180 gms. glucose yields 264 gms. CO_2 in the process of respiration.

Therefore, 11.9 gms. CO_2 is the result of the respiration of $\frac{11.9}{264} \times 180 = 8.12$ gms. sugar.

Therefore, at 60° F., in 42 days, 1 kilogram of Delicious apples lose 8.12 gms. sugar or <u>.812%</u> of their fresh weight.
Similarly, at 40° F., the loss in 105 days is <u>1.01%</u>.
Similarly, at 32° F., the loss in 175 days is <u>1.12%</u>.

These data indicate that loss of sugar through respiration in Delicious apples is only a small amount, around 1 per cent of the fresh weight, and that by the time the fruit has reached overripeness at different temperatures fairly similar amounts of sugar have been used up. If a Delicious apple contains 11 per cent sugar these data indicate that by the end of its storage life it has lost only about 9 per cent of the original respirable carbohydrate content present at time of picking.

<u>(d) Changes in soluble pectin content and rate of ripening.</u> The softening of an apple is brought about largely by the hydrolysis of the insoluble protopectin in the cell walls and middle lamella into soluble pectin. By losing the cell wall cementing material, the flesh of the apple gradually becomes softer and more palatable. In order to study rate of soluble pectin formation in relation to temperature of storage, Delicious apples harvested at optimum maturity were held continuously at three temperatures, 60°, 40°, and 32° F. At succeeding periods in the storage life of the fruit, soluble pectin analyses were made and correlated with

the condition of eating ripeness of the fruit at that time. The data are given in Table 15.

Table 15. Effect of storage temperature upon rate of soluble pectin formation, and speed of ripening in Delicious apples.

Weeks in storage	60° F.		40° F.		32° F.	
	Calcium pectate per 16 cc. juice	Condition of fruit	Calcium pectate per 16 cc. juice	Condition of fruit	Calcium pectate per 16 cc. juice	Condition of fruit
	mg.		mg.		mg.	
0	4.9		4.9		4.9	
1	6.6		---		---	
2	7.6	Ripe	---		---	
3	22.1	Moderately mealy	8.1		5.3	
4	22.8		---		---	
6	31.7	Mealy	10.7	Ripe	5.8	
9	----		11.8	Slightly mealy	9.1	Ripe
12	----		17.0		11.0	
15	----		19.9		12.2	
19	----		23.8	Mealy	13.4	

These data illustrate the rate of soluble pectin formation as influenced by temperature. At 60o F. there was about the same pectin value at the end of four weeks as there was in nineteen weeks at 40° F. At the end of nineteen weeks at 32° F. they had about the same soluble pectin value as they did between the second and third week at 60° F., and only slightly more than one-half that of similar fruit held at 40° F. for a similar period of time.

A correlation between the time at which the apples reached eating ripeness, and their rate of softening as measured by soluble pectin values is also evident. Thus, Delicious apples when held continuously at 60° F. became eating ripe in about two weeks' time, and were going distinctly mealy by the third week; when stored at 40° F, they became eating ripe in six weeks' time, and were getting mealy by the ninth week; and when held at 32° F. were eating ripe in nine weeks, and still in reasonably firm condition when removed from cold storage at the end of the nineteenth week.

(e) Disappearance of starch and storage temperature. During the storage seasons of 1939 and 1940, the disappearance of starch was studied in Delicious during ripening at different temperatures. Samples of fruit were held continuously from time of picking at 60°, 40°, and 32° F. With apples stored at 60° F., a starch-iodine test was made at weekly intervals; with apples stored at 40° and 32° F, at three-weekly intervals. To facilitate presentation of the data, the starch-iodine picture obtained each time the test was made, was recorded according to the set of standards shown in Figure 4. The results obtained during the two seasons corresponded closely, and so for the sake of brevity the results obtained in the 1940-41 season only will be given.

In Table 16 it is evident that the rate of starch disappearance follows a very consistent trend, hastening as the temperature of storage increases. At 60° F., each succeeding week found the starch picture advanced one stage.

Table 16. Effect of storage temperature upon rate of starch disappearance and speed of ripening in Delicious apples.

Weeks in storage	60° F.		40° F.		32° F.	
	Starch-iodine number	Condition of fruit	Starch-iodine number	Condition of fruit	Starch-iodine number	Condition of fruit
0	2		2		2	
1	3		-		-	
2	4	Ripe				
3	5	Moderately mealy	2-3		2	
4	6		-		-	
5	6		-		-	
6	7	Mealy	3	Ripe	2-3	
9	-		4	Slightly mealy	3	Ripe
12	-		5-6		4	Ripe
15	-		7		5-6	Ripe
19	-		-	Mealy	7	Ripe

At 40° and 32° F. the change was not so rapid. However, it seemed consistent that when the fruit first reached eating ripeness, regardless of temperature, the starch-iodine picture was at Stage 3 or 4. At these stages the fruit still contained considerable starch. However, the apples remained in firm eating condition until Stage 7 was reached where only a ring of starch remained around the outer periphery of the apple. Tests on numerous commercial lots indicate that when Delicious have reached Stage 6 they should be promptly removed from storage and sold. The application of a chart such as this should prove of great assistance to a storage operator in judging at which time disposal of his Delicious stocks should take place. By cutting samples of apples during the storage season and applying the iodine test, the stage of ripeness of the fruit and its probable holding life may easily be judged.

4. Effect of controlled atmosphere storage on keeping quality of Delicious apples

The Delicious apple is a variety famed for its truly piquant delicious flavor when picked at correct maturity and eaten at the proper stage of ripeness. However, the fruit ripens rather rapidly in storage and soon becomes mealy when removed from storage. Hence it seemed desirable to explore the possibilities of controlled atmosphere storage as a means of retarding rate of ripening of Delicious apples during and after storage.

(a) Regulated ventilation, controlled atmosphere storage 1937-38. Medium size Fancy grade Delicious of optimum maturity picked October 16 were used for the experiment. Eight kilograms of fruit were placed in the storage containers within a day of picking. Three "natural build-up" carbon dioxide concentrations were used: 5, 7.5, and 10 per cent. Duplicate lots were held in these atmospheres at each of two temperatures, 40° and 32° F. The fruit was removed to the ripening room at 60° F. on March 23 and examined at that time and at succeeding weekly intervals.

The small amounts of fruit available for examination from each treatment limited the sample of apples used at each examination to not more than ten apples. As a consequence, there is some variation in results which must be taken into consideration in evaluating the data. Despite this variation a number of interesting and consistent facts were observed which are summarized in Table 17.

Table 17. Influence of regulated ventilation controlled atmosphere storage on Delicious held at 32° and 40° F.

Lot no.	Date examined	Gas mixture O_2	Gas mixture CO_2	Firmness	Scald	Flesh browning	Flavor
	1938			lb.	%	%	
32° F.							
13	Mar. 23	10.0	5.0	13.5	5	--	Good
	" 30	----	---	12.1	19	--	Off, mealy
	Apr. 4			----	Over	--	Mealy
14	Mar. 23	16.0	5.0	13.2	0	--	Good
	" 30			12.0	45	--	Off, slightly mealy
	Apr. 4			----	Over	--	Mealy
15	Mar. 23	13.5	7.5	14.8	0	--	Good
	" 30			12.2	22	--	Off, slightly mealy
	Apr. 4			----	Over	--	Mealy
16	Mar. 23	13.5	7.5	14.3	2	--	Good
	" 30			11.9	8	--	Off, slightly mealy
	Apr. 4			----	Over	--	Mealy
17	Mar. 23	11.0	10.0	15.2	0	--	Good
	" 30			11.8	13	--	Off, slightly mealy
	Apr. 4			----	Over	25	Mealy
18	Mar. 23	11.0	10.0	15.5	0	--	Good
	" 30			11.7	10	--	Off, slightly mealy
	Apr. 4			----	Over	25	Mealy

Table 17 continued.

Lot no.	Date examined	Gas mixture		Firm-ness	Scald	Flesh brown-ing	Flavor
		O_2	CO_2				
	1938			lb.	%	%	
32° F.							
Check	Mar. 23	air		16.0	0	--	Fair to good
	" 30			14.4	5	--	Fair
	Apr. 4			12.9	0	--	Poor, mealy
	" 14			11.4	7	--	Poor, mealy
40° F.							
7	Mar. 23	16.0	5.0	12.1	30	--	Good, mealy
	" 30			9.5	68	--	Off, mealy
	Apr. 4			----	Over	--	Mealy
8	Mar. 23	16.0	5.0	11.8	28	--	Good, mealy
	" 30			9.9	64	--	Off, mealy
	Apr. 4			----	Over	--	Mealy
9	Mar. 23	13.5	7.5	13.8	30	--	Fair, slightly mealy
	" 30			10.2	54	--	Off, slightly mealy
	Apr. 4			----	Over	--	Mealy
10	Mar. 23	13.5	7.5	13.9	30	--	Fair, mealy
	" 30			9.7	47	--	Off, mealy
	Apr. 4			----	Over	--	Mealy
11	Mar. 23	11.0	10.0	13.6	30	--	Good
	" 30			11.2	36	--	Off, slightly mealy
	Apr. 4			----	Over	--	Mealy
12	Mar. 23	11.0	10.0	14.0	29	--	Good
	" 30			10.8	69	--	Off, slightly mealy
	Apr. 4			----	Over	--	Mealy

Flavor. On the day of removal from storage, all Delicious which had been held in controlled atmospheres were reasonably good in flavor, but when examined a week later had a disagreeable "off" flavor and were decidedly mealy. Check Delicious held in air at 32° F. after a week at 60° F. were still fair in flavor and had not commenced to show mealiness.

Firmness. At time of removal from storage, fruit held at 32° F. was several pounds firmer than that held at 40° F. Check fruit held in air at 32° F. was the firmest of the lot. Of the fruit stored in controlled atmospheres, that held at 32° F. with 7.5 and 10 per cent CO_2 was firmer than other lots. A week after removal from storage, fruit held at 32° F. was still firmer than that held at 40° F.

Scald. Scald in varying amounts was found on all fruit stored in CO_2 mixtures, but was negligible in check fruit in oiled wraps. In all lots of fruit scald increased in amount after removal from cold storage. Scald on fruit held at 32° F. was only slight in amount in comparison with fruit held at 40° F.

Flesh browning. In fruit given the 10 per cent CO_2 treatment at 32° F., a browning of the flesh occurred in about 25 per cent of the apples, suggesting some kind of poisoning of the tissue due to the high CO_2 concentration at low temperature.

(b) Controlled atmosphere storage of Delicious 1938-39. For this study a representative sample of Delicious was obtained by harvesting a quantity of Extra Fancy grade fruit from each of thirty different trees in the Iowa Agricultural Experiment Station orchard. In making up each storage sample, two apples from each tree were included, making a total weight of about 8 kilograms. The apples were wrapped in oil wraps with a few left unwrapped to serve as a check on scald development. After enclosing the fruit in storage containers as described under "Methods" the fruit was placed at two temperatures, 40° and 32° F., and for each temperature and each gas mixture there were duplicate lots of apples. The following three atmospheres were used in comparison with air:

Treatment	CO_2	O_2	N_2
1	5.0	2.5	92.5
2	0.0	2.5	97.5
3	5.0	25.0	70.0
4 (air)	0.0	20.0	80.0

The apples remained in these atmospheres from October 9 to February 27 at which time they were removed to air at 65° F. for examination. A day following removal to air, a rating of the fruit was made by six examiners working independently on samples identified only by lot numbers. Results of pressure tests and quality ratings are given in Table 18.

At this examination, all controlled atmosphere samples, whether at 40° or 32° F., were of good flavor, although fruit of No.3 treatment was getting mealy. The air-stored fruit at 32° F. also was good, but the air-stored fruit at 40° F. was mealy and overripe with the characteristic "off" flavor of overripe Delicious. There was a distinct difference in ground color of the skin of the unblushed side of the apples between the fruit stored in air or under No.3 treatment, and that stored under reduced oxygen in No.1 and No.2 treatments.

Table 18. Effect of controlled atmosphere storage upon firmness of Delicious apples when removed to air at 65° F. on February 27, 1939.

Sample number	Storage temperature	Treatment	Firmness	Flavor	Ground color
	°F.		lb.		
1a	40	2.5% O_2	10.3	Good	Light green
1b	40	5.0% CO_2	10.3	"	" "
1c	32	92.5% N_2	11.7	"	" "
1d	32		12.3	"	" "
2a	40	2.5% O_2	9.5	Good	Light green
2b	40	0.0% CO_2	9.5	"	" "
2c	32	97.5% N_2	12.0	"	" "
2d	32		11.3	"	" "
3a	40	25.0% O_2	8.7	Good	Yellow
3b	40	5.0% CO_2	7.9	"	"
3c	32	70.0% N_2	10.8	"	"
3d	32		9.8	"	"
4a	40	Air	7.5	Stale overripe	Yellow
4b	40		7.8	"	"
4c	32		11.1	Good	"
4d	32		11.1	"	"

Note: "a" and "b" are duplicate treatments at 40° F.
"c" and "d" are duplicate treatments at 32° F.

Of the controlled atmosphere samples at both 32° and 40° F., the fruit least ripe to taste was treatment No.2 (97.5 per cent N_2, 2.5 per cent O_2). At 32° F. fruit of this series was still slightly starchy to taste and less ripe than air checks at the same temperature. However, the fruit in treatment No.3 (70 per cent N_2, 25 per cent O_2, 5 per cent CO_2) at both 40° and 32° F., while still in good eating condition, was on the verge of mealiness and distinctly softer than the other lots.

With the exception of fruit of treatment No.3, which was softer than the other lots, no differences in firmness existed between the different lots at 32° F. At 40° F. the fruit of No.1 treatment was firmest followed by that of No.2 treatment and both were distinctly firmer than either the air checks or treatment No.3. At 40° F. the air checks and No.3 treatment were of approximately the same firmness. No scald in oil wrapped or unwrapped fruit was observed nor were any other physiological disorders evident in the different lots of fruit.

Acidity values of storage samples, February 27. Total acidity and active acidity (pH) were determined on February 27, the day the fruit was removed to air. These data are given in Table 19.

There is little indication that storage procedure or temperature appreciably affected acidity values, except that in treatments Nos. 3 and 4, acidity was somewhat less than in treatments Nos. 1 and 2. As compared with acidity measurements taken at time of picking, the figures showed some changes, most conspicuously the increase in pH from 4.09 to about 4.90.

Table 19. Effect of controlled atmosphere storage upon acidity values of Delicious apples at time of removal to air, February 28, 1939.

Sample number	Storage temperature	Treatment	Acidity	
			pH	Total *
	°F.			
1a	40	2.5% O_2	4.84	2.65
1b	40	5.0% CO_2	4.89	2.75
1c	32	92.5% N_2	4.89	2.55
1d	32		4.89	2.55
2a	40	2.5% O_2	4.88	2.55
2b	40	0.0% CO_2	4.87	2.50
2c	32	97.5% N_2	4.89	2.55
2d	32		4.90	2.55
3a	40	25.0% O_2	4.90	2.30
3b	40	5.0% CO_2	4.89	2.45
3c	32	70.0% N_2	4.95	2.25
3d	32		4.92	2.35
4a	40	Air	4.84	2.60
4b	40		4.84	2.50
4c	32		5.02	2.10
4d	32		5.04	1.90
		At picking	4.09	2.70

* Expressed as cc. .05 N NaOH to titrate 12.5 cc. juice diluted to 50 cc.

Examination of fruit fourteen days after removal from storage. Samples of fruit taken from storage February 27 were held in air at 65° F. until March 13 (fourteen days later) to simulate market conditions, and were then re-examined. The data are given in Table 20.

The fruit which had been held in controlled atmospheres at both 40° and 32° F., and in air at 32° F., was all of good flavor, although some lots were better than others.

Table 20. Condition of Delicious apples fourteen days after removal from controlled atmosphere storage to air at 65° F., March 13, 1939.

Sample number	Storage temperature	Treatment	Flavor	Mealiness	Firmness
	°F.				lb.
1a	40	2.5% O_2	Fair	Moderate	7.1
1b	40	5.0% CO_2	"	Excessive	6.8
1c	32	92.5% N_2	Good	Slight	8.4
1d	32		"	"	8.6
2a	40	2.5% O_2	Good	Moderate	7.3
2b	40	0.0% CO_2	"	"	7.6
2c	32	97.5% N_2	"	None	9.4
2d	32		"	"	10.0
3a	40	25.0% O_2	Poor	Excessive	6.0
3b	40	5.0% CO_2	"	"	6.0
3c	32	70.0% N_2	Fair	"	7.2
3d	32		"	"	7.2
4a	40	Air	Poor	Excessive	6.6
4b	40		"	"	6.4
4c	32		Fair	Slight	8.1
4d	32		"	"	8.8

The 40° F. air sample was definitely overripe. The best fruit was that of series 2 (97.5 per cent N_2, 2.5 per cent O_2) held at 32° F. It was crisp, juicy and of good flavor, and even two weeks later (March 27) was still in fairly good condition without evidence of much mealiness. Next best in quality to treatment No.2, were No.1 and No.4 treatments held at 32° F. At both 40° and 32° F., treatments Nos. 1 and 3, especially No.3, were soft and mealy although still of satisfactory flavor. At 40° F. treatment No.2 was firmest followed by treatment No.1. Treatments No.3 and 4 (air check) were both much softer than No. 1 and 2.

It would appear that treatment No.3 (70 per cent N_2, 25 per cent O_2, 5 per cent CO_2) was actually harmful to the fruit at both 40° and 32° F. since it hastened the onset of mealiness.

Sucrose, reducing sugars, starch, and weight of alcohol-leached residue of fruit stored in controlled atmospheres. To determine what changes had taken place in sugar content of fruit stored under different atmospheres, duplicate analyses from each lot were made for reducing sugar and sucrose, and starch. In addition, the dry weights of the tissue remaining after alcohol extraction of the various samples for sugars and other soluble materials were determined. This was done principally to ascertain the decrease in insoluble material between time of harvest and time of removal of the fruit from storage. The difference, which is considerable, can be assumed with only a small degree of error, to be due to starch present at picking, but largely, if not entirely, hydrolyzed to glucose during storage. These data are given in Tables 21, 22, 23, and 24.

From Table 21 it is evident that controlled atmosphere storage did not have any consistent or appreciable effect upon the sugar fractions of Delicious apples. Such differences as did occur could more safely be assigned to experimental error. It was noticeable, however, that all

Table 21. Effect of controlled atmosphere storage on sugar content of Delicious apples when removed from storage, February 27, 1939.

Sample number	Storage temperature	Treatment	Percentage sugar (fresh weight basis)		
			Reducing	Sucrose	Total
	°F.		%	%	%
Fall 1938		At picking	6.84	2.26	9.10
1a	40	2.5% O_2	9.40	0.99	10.39
1b	40	5.0% CO_2	9.36	1.22	10.58
1c	32	92.5% N_2	9.00	1.75	10.75
1d	32		8.88	1.37	10.25
2a	40	2.5% O_2	9.44	1.10	10.54
2b	40	0.0% CO_2	9.36	1.18	10.54
2c	32	97.5% N_2	8.80	1.75	10.53
2d	32		8.88	1.63	10.51
3a	40	25.0% O_2	8.56	1.63	10.19
3b	40	5.0% CO_2	8.88	1.41	10.29
3c	32	70.0% N_2	8.70	1.73	10.43
3d	32		8.68	1.67	10.35
4a	40	Air	9.32	1.60	10.92
4b	40		----	----	-----
4c	32		8.80	1.63	10.43
4d	32		8.70	1.99	10.69

lots stored at 40° F. had more glucose and less sucrose than corresponding lots held at 32° F. The "fall" sample taken at picking time showed a low total sugar value, since at that time a fair amount of starch was present, which later during storage became hydrolyzed to glucose. It is evident also that part of the sugar in the form of sucrose at picking time later became converted to reducing sugar.

Fifteen days after removal of the apples from storage, samples were again preserved for analysis. Sugar determinations on these samples yielded the following results:

Table 22. Effect of controlled atmosphere storage on sugar content of Delicious apples fifteen days after removal to air, March 14, 1939.

Sample number	Storage temperature	Treatment	Percentage sugar (fresh weight basis)		
			Reducing	Sucrose	Total
	°F.		%	%	%
Fall 1938		At picking	6.84	2.26	9.10
1a	40	2.5% O_2	9.28	1.22	10.50
1b	40	5.0% CO_2	9.44	1.41	10.86
1c	32	92.5% N_2	9.12	1.60	10.72
1d	32		9.08	1.52	10.60
2a	40	2.5% O_2	9.16	1.60	10,76
2b	40	0.0% CO_2	9.40	1.14	10,54
2c	32	97.5% N_2	8.92	1.67	10.59
2d	32		8.84	1.64	10.48
3a	40	25.0% O_2	9.00	1.18	10.18
3b	40	5.0% CO_2	8.96	1.22	10.18
3c	32	70.0% N_2	8.64	1.67	10.31
3d	32		8.64	1.69	10.33
4a	40	Air	8.96	1.16	10.12
4b	40		----	----	-----
4c	32		8.88	1.33	10.21
4d	32		8.52	1.67	10.19

As compared with the analyses in Table 21, little change in the composition of the fruit can be noted during the fifteen-day interval after removal from storage. Sucrose was still lower and reducing sugar higher in the fruit stored at 40° F. as compared with fruit stored at 32° F.

Starch. In Table 23 are shown starch analyses taken on finely ground samples of tissue residue remaining after alcoholic extraction for soluble materials. The data deal with starch content at picking, at time of removal from storage, and fifteen days after removal from storage.

Table 23. Effect of controlled atmosphere storage upon starch changes in Delicious apples expressed as per cent of fresh weight.

Gas mixture	Storage temperature	Starch, as per cent of fresh weight		
		At start Oct.8	Feb.27	March 14
	°F.	%	%	%
No.1 - 97.5% N_2, 2.5% O_2, 5.0% CO_2	40	.891	.1435	.1058
	32	.891	.2110	.1612
No.2 - 97.5% N_2, 2.5% O_2, 0.0% CO_2	40	.891	.1510	.1104
	32	.891	.1750	.1432
No.3 - 70.0% N_2, 25.0% O_2, 5.0% CO_2	40	.891	.1210	.1280
	32	.891	.1180	.1104
No.4 - Air	40	.891	.1330	.1443
	32	.891	.1870	.1496

It is evident from these data that a small amount of starch persisted in the tissue of all samples even up to two weeks after removal of the fruit from storage. There was no notable or consistent decrease in starch from February 27 to March 14. The presence of a small amount of starch even in fully ripe apples is not unusual, as indicated by the starch-iodine reaction on cut halves of Delicious apples. It is notable from these figures that there was a large reduction in starch content from time of picking

(.891 per cent) to the end of the storage period (about .13 per cent). This starch is hydrolyzed to glucose, and sugar values of the apples after storage are correspondingly increased.

<u>Alcohol-insoluble residue</u>. In Table 24 are shown the values for insoluble residue remaining after alcohol extraction of the apple tissue samples.

Table 24. Effect of controlled atmosphere storage upon insoluble residue remaining after extraction of apple tissue for removal of substances soluble in 80 per cent ethyl alcohol.

Sample number	Storage temperature	Treatment	Percentage insoluble residue in samples preserved on *	
			Feb.28	March 15
	°F.		%	%
1a	40	2.5% O_2	1.91	1.86
1b	40	5.0% CO_2	1.77	1.87
1c	32	92.5% N_2	2.05	1.95
1d	32		1.95	1.95
2a	40	2.5% O_2	1.81	1.92
2b	40	0.0% CO_2	1.75	1.85
2c	32	97.5% N_2	1.95	1.91
2d	32		1.95	1.94
3a	40	25.0% O_2	1.93	1.82
3b	40	5.0% CO_2	1.82	1.86
3c	32	70.0% N_2	1.86	1.91
3d	32		1.86	1.92
4a	40	Air	1.87	1.89
4b	40		1.85	1.90
4c	32		1.96	1.93
4d	32		1.85	1.93

* A check sample analysed at harvest time contained 3.06 per cent alcohol-insoluble residue.

It is evident that no significant differences in amount of insoluble residue could be attributed to the storage treatment given the fruit. Such differences as exist fall within the range of experimental error.

(c) Controlled atmosphere storage of Delicious, 1940-41. In the storage season of 1940-41 another controlled atmosphere storage experiment was carried out. This was similar to the one just reported on and done at Iowa State College, except that it was carried out at the Dominion Experimental Station, Summerland, B. C. The same atmospheres and similar techniques were used as in 1938-39.

The fruit for these experiments was of Extra Fancy quality, harvested October 9, and stored October 11. The fruit sample placed in each can consisted of an equal quantity of medium sized apples from three different trees, a total of about 45 apples weighing 8 kilograms. The apples were unwrapped except for six apples in each can which were oil wrapped as a check for scald control.

The apples were removed from storage along with air stored checks on February 17, 1941, and held in a ripening room at 65° F. for examination at intervals. At the time the fruit was removed from storage and seventeen days later, on March 6, pressure and organoleptic tests were made, and acidity and soluble pectin content determined. In addition, 100-gram representative samples of tissue from fifteen fruits were preserved in boiling ethyl alcohol for future analysis. At the time the fruit was removed the iodine test was applied to the different lots of fruit to ascertain the presence of unhydrolyzed starch.

Quality sampling test. One day after removal from controlled atmosphere storage, the different samples of fruit together with air stored checks were laid out for examination identified only by reference numbers. The samples were evaluated by a panel of six judges for crispness of texture, flavor, and appearance. Firmness and flavor were each rated on the basis of 10 as a perfect score. The data which follow indicate the average ratings given.

A rating of this kind is necessarily susceptible to inaccuracies of judgment, but does serve as a useful index of fruit quality. It was striking that at both 32° and 40° F., numbers 1 and 2 treatments resulted in fruit of excellent firmness, whereas treatments 3 and 4 gave fruit judged to be much softer, in the opinion of the author, definitely turning mealy. Flavor was also judged to be better in the first two than in the last two treatments, with the exception of fruit in 3d, which for some reason received a very high rating. The pronounced aldehyde flavor of Delicious becoming overripe was obvious in apples from treatments 3 and 4. It was interesting, however, to note

Table 25. Effect of controlled atmosphere storage on condition of Delicious apples as rated by a panel of judges, February 17, 1941.

Sample number	Storage temperature	Treatment	Firmness 1-10	Flavor 1-10	Ground color
	°F.				
1a	40	2.5% O_2	8.6	7.6	light green
1b	40	5.0% CO_2	9.0	6.6	" "
1c	32	92.5% N_2	9.1	5.0	" "
1d	32		9.3	6.8	" "
2a	40	2.5% O_2	8.5	8.6	light green
2b	40	0.0% CO_2	7.0	6.3	" "
2c	32	97.5% N_2	8.3	6.3	" "
2d	32		8.7	7.1	" "
3a	40	25.0% O_2	5.5	6.0	yellow
3b	40	5.0% CO_2	4.1	4.1	"
3c	32	70.0% N_2	6.0	6.3	"
3d	32		7.1	8.2	"
4a	40	Air	3.9	5.1	yellow
4b	32		6.0	5.2	"

that with one exception none of the controlled atmosphere treatments produced any undesirable "off" flavors in the fruit. The one exception was lot 1a which after two days at 60° F. became quite normal in flavor. No apple scald had developed in any of the apples either wrapped or unwrapped. The effect of higher oxygen concentration upon transformation of skin color was noted in treatments 3 and 4 which showed fruit of yellow ground color as compared with light green ground color in the low oxygen treatments 1 and 2.

<u>Firmness by pressure test.</u> Firmness of the fruit one day after removal from controlled atmospheres as judged

by the Ballauf pressure tester was recorded with ten representative apples from each sample, and is set forth in Table 26.

Table 26. Effect of controlled atmosphere storage upon firmness of Delicious apples when removed to air, February 17, 1941.

Sample number	Storage temperature	Treatment	Firmness
	°F.		lb.
1a	40	2.5% O_2	12.4
1b	40	5.0% CO_2	12.9
1c	32	92.5% N_2	13.6
1d	32		13.8
2a	40	2.5% O_2	12.0
2b	40	0.0% CO_2	11.7
2c	32	97.5% N_2	12.5
2d	32		13.3
3a	40	25.0% O_2	11.3
3b	40	5.0% CO_2	10.2
3c	32	70.0% N_2	11.6
3d	32		11.4
4a	40	Air	9.2
4b	40		9.2
4c	32		10.8
4d	32		10.7

These data confirm the observations in Table 25 since they show that fruit from treatments 1 and 2 was considerably firmer than that from treatments 3 and 4. The fruit from "c" and "d" treatments which was stored at 32° F. was somewhat firmer than that held at 40° F. ("a" and "b" treatments) especially the air stored sample.

Soluble pectin, starch, and acidity values of controlled atmosphere storage fruit when removed from storage. Possibly the most accurate test for changes in firmness and cell wall structure in fruit is the determination of degree of protopectin hydrolysis to the soluble pectin form, (7, 8, 15, 20) which indicates the degree to which the middle lamellae of the cell walls have become hydrolyzed and broken down, and consequently the progress of softening of the flesh. Acidity changes as a rule give some indication of progress of ripening, since acid tends to disappear during the ripening process. Starch hydrolysis also provides a useful guide as to the stage of ripeness attained since complete absence of starch (as judged by the iodine reaction) is associated with full ripeness. These data are given in full in Table 27.

It is clearly indicated by the data of Table 27 that protopectin hydrolysis of cell wall thickenings to the soluble pectin form was markedly retarded by each of the three controlled atmospheres in comparison with air storage. This was most marked in the No.2 treatment. In the controlled atmospheres, soluble pectin values at 32° F. were just slightly lower than at 40° F., but in air stored fruit approximately one-half that found at 40° F. It is interesting to note that fruit stored in controlled atmospheres showed close to the same soluble pectin value (4.9 mg.), at time of removal to air, as found at time of picking. In other words, practically no protopectin hydrolysis had taken place with the fruit

Table 27. Effect of controlled atmosphere storage upon soluble pectin content, acidity, and starch values of Delicious apples at time of removal to air, February 18, 1941.

Sample number	Storage temperature	Treatment	Soluble pectin *	Acidity		Starch-iodine reaction stage (See Fig.4)
				pH	Total ≠	
	°F.		mg.		cc.	
1a	40	2.5% O_2	6.2	4.42	5.7	7
1b	40	5.0% CO_2	6.8	4.36	5.6	7
1c	32	92.5% N_2	6.4	4.43	5.7	7
1d	32		5.4	4.41	6.0	7
2a	40	2.5% O_2	4.2	4.44	5.5	7
2b	40	0.0% CO_2	5.2	4.41	5.8	7
2c	32	97.5% N_2	3.2	4.48	5.8	6
2d	32		4.5	4.46	5.8	6
3a	40	25.0% O_2	9.3	4.47	4.8	8
3b	40	5.0% CO_2	8.3	4.43	4.6	8
3c	32	70.0% N_2	5.2	4.43	4.9	7
3d	32		5.4	4.49	5.2	7
4a	40	Air	24.6	4.63	5.0	8
4b	40		23.1	4.52	5.2	8
4c	32		11.1	4.49	5.6	7
4d	32		15.7	4.55	5.6	7
Check	Fruit at picking		4.9	4.32	7.7	2

* expressed as calcium pectate per 16 cc. juice.
≠ expressed as .05 N NaOH to titrate 12.5 cc. juice diluted to 50 cc.

stored in controlled atmospheres during a storage period of over four months.

Starting with an initial active acidity value (pH) of 4.32 and total acidity value of 7.7 at time of picking, by the end of the storage period these values had dropped to around pH 4.45 and 5.5 for total acidity. The air stored fruit at 40° F. and the fruit from treatment 3 with high oxygen showed the greatest acid losses. The treatment which produced least acid loss was No.2 (2.5% O_2 and 97.5% N_2). It will be noted that results with duplicate "a" and "b" treatments did not always check. This is probably due to variability in the samples.

Apples from each lot were cut and dipped in iodine solution, and the amount of starch present recorded. Traces of starch in the outer periphery of the cortex were noted in most lots, but only in samples 2c and 2d were any appreciable quantities of starch present. Organoleptic tests and pectin values suggested also that these two lots were least advanced in degree of ripeness.

Examination of fruit nine days after removal from storage. Nine days after the Delicious were removed from controlled atmosphere storage to air at 65° F. they were again examined for eating quality and firmness. Lots 1 and 2 had retained their firmness and crispness to a marked degree whereas Lot 3 was going mealy and the air stored samples at 32° and 40° F. were definitely mealy. Moreover, the air stored samples, particularly those held at 40° F., had taken on the typical stale overripe Delicious flavor.

Examination of fruit seventeen days after removal from storage. Seventeen days after removal from storage the fruit was again given an extensive examination. Pressure tests and chemical determinations were made similar to those taken at time of removal from storage. Results of sampling tests to determine flavor, mealiness, and firmness are given in Table 28.

Table 28. Condition of Delicious apples seventeen days after removal from controlled atmosphere storage to air at 65° F., March 6, 1941.

Sample number	Storage temperature	Treatment	Flavor	Mealiness	Firmness
	°F.				lb.
1a	40	2.5% O_2	5	Excessive	9.9
1b	40	5.0% CO_2	5	"	8.5
1c	32	92.5% N_2	5	"	9.6
1d	32		5	"	9.2
2a	40	2.5% O_2	5	Excessive	9.1
2b	40	0.0% CO_2	6	Moderate	9.6
2c	32	97.5% N_2	7	"	10.5
2d	32		7	"	9.9
3a	40	25.0% O_2	5 stale	Excessive	7.7
3b	40	5.0% CO_2	5 "	"	7.9
3c	32	70.0% N_2	5	"	9.2
3d	32		5	"	8.6
4a	40	Air	3 stale	Excessive	8.7
4b	40		3 "		8.7
4c	32		4 "	Excessive	8.8
4d	32		4 "		8.8

These data indicate that the initial advantage in firmness of the fruit stored in controlled atmospheres had largely disappeared by March 6, seventeen days later. All lots except the No.2 treatments were definitely mealy, and a stale objectionable aldehyde flavor had developed in Lots 3a, 3b, and 4a, 4b, 4c, and 4d. The fruit from treatments

2c and 2d (2.5% O_2 and 97.5% N_2, at 32° F.) and treatment 2b at 40° F. was considerably less mealy than the other lots and superior in flavor.

As judged by the pressure tester, the fruit of treatment 2 was also firmer than that of the other lots. The fruit receiving the high oxygen treatment at 40° F. (Nos. 3a, 3b) was decidedly the softest of all three lots. Air stored fruit was softer than fruit given treatments 1 and 2.

<u>Soluble pectin and acidity values of controlled atmosphere storage Delicious seventeen days after removal to air at 65° F.</u> When the fruit was examined on March 6, seventeen days after removal from storage, soluble pectin and acidity values were again determined. These data follow in Table 29.

By comparing these data with those given in Table 27, striking changes are evident, especially the pectin values which increased four to six times during the seventeen days at 65° F. The fruit given No.3 treatment showed by far the highest soluble pectin content, and this was in agreement with the pressure test determinations taken on this fruit at that time. Pectin content in the 40° F. air stored fruit increased only slightly whereas at 32° F. the pectin values slightly more than doubled..

Active acidity (pH) decreased quite markedly, particularly in the air stored fruit at 32° F. whereas total

Table 29. Effect of controlled atmosphere storage upon the soluble pectin content and acidity values of Delicious apples seventeen days after removal from storage, March 6, 1941.

Sample number	Storage temper-ature	Treatment	Soluble pectin *	Acidity	
				pH	Total ≠
	°F.		mg.		cc.
1a	40	2.5% O_2	26.7	4.70	5.3
1b	40	5.0% CO_2	23.5	4.66	5.0
1c	32	92.5% N_2	25.6	4.71	5.9
1d	32		28.7	4.62	5.8
2a	40	2.5% O_2	25.3	4.69	5.6
2b	40	0.0% CO_2	27.1	4.71	5.0
2c	32	97.5% N_2	22.4	4.72	5.1
2d	32		21.6	4.72	4.9
3a	40	25.0% O_2	38.5	4.77	4.8
3b	40	5.0% CO_2	37.9	4.72	4.9
3c	32	70.0% N_2	25.1	4.76	4.6
3d	32		33.6	4.74	4.7
4a	40	Air	29.9	4.74	5.2
4b	40		29.4	4.72	5.1
4c	32		30.2	4.88	4.6
4d	32		32.1	4.81	5.5

* expressed as calcium pectate per 15 cc. juice.
≠ expressed as .05 N NaOH to titrate 12.5 cc. juice diluted to 50 cc.

acidity declined slightly. These changes did not appear to be correlated significantly with any particular storage treatment.

<u>Sucrose, reducing sugars, and weight of alcohol-leached residue of fruit stored in controlled atmospheres.</u> To determine what changes had taken place in the sugar content of the fruit stored under different atmospheres, duplicate analyses from each lot were made for reducing sugar and

sucrose. In addition the dry weights of the alcohol-leached tissue samples were obtained, principally to ascertain the decrease in insoluble residue between harvest time and the time the fruit was removed from storage in February. The difference which is large can be assumed, without appreciable error, to be due to starch present at picking, but largely, if not entirely, hydrolyzed to glucose during storage. These data are given in Tables 30, 31, and 32.

Table 30. Effect of controlled atmosphere storage on sugar content of Delicious apples when removed from storage, February 17, 1941.

Sample number	Storage temperature	Treatment	Percentage sugar (fresh weight basis)		
			Reducing	Sucrose	Total
	°F.		%	%	%
Fall 1941, At picking			6.65	2.52	9.17
1a	40	2.5% O_2	9.11	1.52	10.63
1b	40	5.0% CO_2	9.57	1.60	11.10
1c	32	92.5% N_2	8.64	2.24	10.88
1d	32		8.94	2.60	11.54
2a	40	2.5% O_2	9.36	2.16	11.52
2b	40	0.0% CO_2	9.11	1.80	10.91
2c	32	97.5% N_2	8.78	2.36	11.14
2d	32		8.78	2.20	10.98
3a	40	25.0% O_2	9.32	1.60	10.92
3b	40	5.0% CO_2	9.36	1.24	10.60
3c	32	70.0% N_2	8.69	2.36	11.05
3d	32		8.57	2.64	11.21
4a	40	Air	8.27	2.72	10.99
4b	40		----	----	-----
4c	32		8.94	2.12	10.06
4d	32		9.32	2.40	11.72

From Table 30 it is evident that there was some variation between lots as to reducing sugar and sucrose content, but there does not seem to be any significant effect that could be attributed to the treatments themselves. Rather it would appear that variations existing between duplicate samples (i.e. "a" and "b", "c" and "d" samples), and different treatments (i.e. 1, 2, 3, and 4) could be more reasonably assigned to slight variations in experimental samples.

Unless respiration rates were very markedly reduced by controlled atmospheres, not much change in total sugar content could be expected, for by calculation it has been shown that a Delicious apple loses only about 9.0 per cent of its sugar content through respiration during a period of six months' storage at 32° F. (See page 73) It has been shown by Kidd and West (29) that there is some reduction in respiration rate of apples in controlled atmosphere storage.

It does seem fairly consistent, however, that the sucrose content of apples stored at 32° F. was a little higher than that of those at 40° F. It is interesting also to note the low total sugar value for the sample taken at picking. This value (6.65 per cent) is low in comparison with the samples taken after storage, because in these samples, approximately 2.5 per cent of starch present in the apples at picking had been hydrolyzed over to reducing sugar.

In Table 31 are shown the sugar values for the different samples seventeen days after removal from storage. These figures again indicate little significant difference between treatments and on the whole tend to show a slightly higher sugar content than at the time of removal from storage, probably because of a small degree of shrivelling.

Table 31. Effect of controlled atmosphere storage on sugar content of Delicious apples seventeen days after removal from storage, March 6, 1941.

Sample number	Storage temperature	Treatment	Percentage sugar (fresh weight basis)		
			Reducing	Sucrose	Total
	° F.		%	%	%
1a	40	2.5% O_2	10.20	1.68	11.88
1b	40	5.0% CO_2	9.66	2.16	11.82
1c	32	92.5% N_2	9.32	2.20	11.52
1d	32		9.36	2.08	11.44
2a	40	2.5% O_2	9.70	1.68	11.38
2b	40	0.0% CO_2	9.83	2.04	11.87
2c	32	97.5% N_2	9.45	1.84	11.29
2d	32		8.94	2.68	11.62
3a	40	25.0% O_2	9.20	1.88	11.08
3b	40	5.0% CO_2	9.32	2.08	11.40
3c	32	70.0% N_2	9.36	1.84	11.20
3d	32		9.49	1.92	11.41
4a	40	Air	10.20	1.56	11.76
4b	40		9.37	2.04	11.41
4c	32		9.37	2.08	11.45
4d	32		8.36	3.20	11.56

In Table 32 the alcohol-insoluble residue after extraction of the 100-gram sample of tissue is shown. It is apparent from these data that the alcohol-insoluble residue of the fruit was approximately 2 per cent, subject to variations between samples. The weights of the residue on March 6 were consistently less than on February 17, this loss probably being due to pectin compounds in the cell walls being hydrolyzed over to the soluble form, as reported under pectin analyses. The comparison with the sample taken in the fall

Table 32. Effect of controlled atmosphere storage upon insoluble residue remaining after alcohol extraction of apple tissue for removal of substances soluble in 80 per cent ethyl alcohol.

Sample number	Storage temperature	Treatment	Percentage insoluble residue in samples preserved on	
			Feb. 17	March 6
			%	%
1a	40	2.5% O_2	1.95	1.88
1b	40	5.0% CO_2	2.01	1.80
1c	32	92.5% N_2	2.01	1.84
1d	32		2.16	1.87
2a	40	2.5% O_2	1.95	1.78
2b	40	0.0% CO_2	1.97	1.75
2c	32	97.5% N_2	1.97	1.85
2d	32		2.00	1.84
3a	40	25.0% O_2	1.95	1.78
3b	40	5.0% CO_2	1.80	1.74
3c	32	70.0% N_2	2.07	1.80
3d	32		1.84	1.78
4a	40	Air	1.81	1.83
4b	40		2.00	1.88
4c	32		2.02	1.87
4d	32		2.26	1.87

Note: A check sample analysed at harvest time contained 4.32 per cent insoluble residue.

at time of picking (4.32 per cent) indicates that roughly 2.5 per cent of the starch present at harvest time was hydrolyzed during storage to reducing sugar.

5. Waxing of Delicious apples in relation to keeping quality.

Interesting claims have been made by commercial companies concerning the use of wax emulsions for retarding ripening and controlling mealiness in Delicious apples. To investigate these claims several years' experiments have been carried out with the wax emulsion supplied by a commercial manufacturer. Composition of the wax emulsion and method of application are found under "Procedure" on page 22. The composition of the material was similar in the three different seasons, except that in 1939 the emulsifying agent was sodium oleate instead of triethanolamine used in 1936 and 1937. In 1936, a 6 per cent wax emulsion was used; in 1937, 3, 4, and 5 per cent emulsions; and in 1939, a 5 per cent emulsion. Extensive data have been accumulated, but only a summary of the results is presented herewith.

In 1936, the 6 per cent wax emulsion had a pronounced effect upon delaying the onset of mealiness and stale flavor in Delicious, prolonging storage life after removal of fruit from 32° to 60° F., to 37 days as compared with 15 days for unwaxed checks. At the end of three weeks, unwaxed fruit was excessively mealy while waxed fruit was still firm and juicy. However, development of a peculiar type of scald was induced by the waxing treatment which gave a scald index of 46 per cent in treated fruit as compared with only 9 per cent in untreated fruit. The scalded areas were somewhat sunken in appearance and set in hard wrinkles, whereas ordinary apple scale leaves the affected areas quite smooth.

Table 33. Effect of wax emulsions upon keeping quality of Delicious stored at 32° F. and then removed to ripening room at 60° F.

Year	Wax concentration	Date removed from cold storage to ripening room	Firmness when removed	Period of good eating condition	Mealiness at end of 3 weeks	Flavor	Scald
	%		lb.	days			%
1936	6	Feb. 11	14.5	37	None	Good	46
	check		14.5	15	Excessive	"	9
1937	3	Mar. 23	14.9	10	Excessive	Poor	68
	4		15.3	10	Moderate	Fair	67
	5		15.8	20	"	"	47
	check		14.7	8	Excessive	Poor	3
1939	5	Feb. 12	12.8	20	*	Fair	0
	check		12.9	20		"	0

* This season fruit did not go mealy.

In the 1937 experiments, 3, 4, and 5 per cent wax emulsions were used to see if lower concentrations of wax emulsion would obviate scald development while at the same time producing the same inhibiting effects upon ripening as noted with the 6 per cent emulsion used the previous year. Scald development was still serious, in fact more serious than that of the previous season. Check fruit had practically no scald. The strength of the emulsion, however, did show an effect on the keeping quality of the fruit, for the apples receiving the 5 per cent wax emulsion remained in good eating condition for 20 days whereas those receiving 3 and 4 per cent emulsion remained in good eating condition only ten days, just slightly more than unwaxed checks.

In 1939 a comprehensive experiment was planned and carried out where maturity at harvest and type of fruit wrap were studied in relation to the use of wax emulsions for Delicious apples. Fruit was harvested at five weekly intervals starting September 26, and stored, waxed and unwaxed, oil wrapped and plain wrapped, at 32° F. The oiled wraps were used to see if the scald produced by the waxing treatment could be controlled by this method. The apples were removed from storage on February 12 to the ripening room and examined at that time, and again after three weeks.

A great volume of data was secured, but due to unusual circumstances, the information sought after was not obtained. In the first place, 1939 being a cool season with rather poor maturity for the Delicious apple, none of the pickings harvested showed any tendency to go mealy. In the second place, scald was not a serious factor in the storage of Delicious or any other variety in the 1939 season. Thirdly, a different emulsifier, sodium oleate, was used in the wax emulsion rather than the triethanolamine used previously. It is quite possible that the change in emulsifying agent was largely responsible for elimination of scald in Delicious waxed in 1939. The responses of the different pickings of waxed and unwaxed Delicious were so similar to each other and to untreated controls, that data for only the October 17 picking are presented in Table 33.

Further information on the effect of the emulsifying agent and oiled wraps will be necessary before commercial evaluation of waxing for Delicious apples can be considered. It might be mentioned that when the wax dries, the coating is so thin as to be imperceptible and in no way impairs the eating quality of the skin. Waxing has not been found to injure the flavor of Delicious apples. It has been estimated by the company who supplied the materials that waxing could be performed for an outlay of two cents per box.

IV. DISCUSSION

The results of this study indicate that poor quality in Delicious apples may be due to unfavorable growing conditions, incorrect maturity at harvest, or improper storage. Quality in this connection refers to presence or absence of characteristic Delicious flavor, and presence or absence of mealiness.

In 1939, when a cool summer and fall prevailed, few Delicious attained superior quality. Actually they never really reached a proper degree of maturity. In the following season (1940) the weather was above average in warmth during summer and fall and fruit of unusually good quality was harvested. Seasonal weather conditions over which the grower has no control can thus influence quality in Delicious very markedly. Moreover, even in good seasons, the fruit in some orchards seldom matures properly whereas in other orchards maturity is perfect.

Immaturely harvested Delicious ripen into fruit of poor flavor. Flavor is a hard thing to describe in any variety—especially Delicious. Attempts in the past have been made to describe flavor in terms of sugar-acid balance (Shaw 58). Chemically speaking this ratio is easy to determine, but from the standpoint of fruit flavor it does not supply much information. Delicious is an apple of average sugar content, but particularly low acid content. During the weeks preceding harvesting, maturity changes occurring in sugar and acid are of very small amount. The odorous constituents of apples have been shown by Power and Chestnut (57) to consist essentially of various esters combined with acetaldehyde. The presence of these odorous constituents in Delicious apples seems especially important in the development of characteristic Delicious flavor. In combination with sugars, acid, tannin, etc., these flavoring principles impart to Delicious its delicate varietal flavor. An interesting chemical study could be made dealing with the metabolism of odorous constituents in Delicious apples.

Harvesting Delicious at the correct stage of maturity seems to assure that these flavoring esters will be present and will develop fully when the fruit reaches eating ripeness. An immaturely picked Delicious will ripen into an edible fruit, but will be sweet and insipid to taste, and will lack characteristic varietal flavor. One who has familiarized himself with the variety can discern at time of picking, by biting into an unripe apple, whether or not the true Delicious flavor is present and will develop upon ripening. Delicious harvested immature seldom become mealy, but when overripe assume the stale flavor characteristic of Delicious past their prime.

In speaking of immaturity it is in order to point out that immature fruit is not always the result of too early picking. Cee grade Delicious which are common on trees poorly thinned or inadequately pruned, or in over-crowded or over-stimulated orchards, are distinctly fruit of low maturity. They have a poor showing of red skin color, a flesh with a greenish tinge particularly around the carpellary bundles, and are almost uniformly lacking in varietal flavor. Orchards surveyed in this investigation, and the general observations of the author indicate that particular attention should be paid to cultural operations with this variety. Best quality Delicious are usually of Extra Fancy or Fancy grade and of 138 or larger size to the bushel box. On mature full-bearing trees, thinning fruits 9 inches apart is often necessary to secure apples of desirable size and color, and may make the difference between good and poor quality.

The best single test for maturity in striped strains of the Delicious apple is probably a good showing of solid red color combined with a flesh color turning from white to cream as described by Strachan (65). The starch-iodine test for maturity in Delicious apples is described, but more comprehensive work will be required before recommendations based upon it may safely be made.

Another factor responsible for poor quality in Delicious is a mealy condition of the flesh which is associated with hydrolysis of the protopectin in the cell walls to the soluble pectin form. This hydrolysis of the cell wall thickenings weakens the cellular organization of the flesh and causes it to become soft and mealy. Chemical analyses of mealy and non-mealy apples indicate no significant differences except in their soluble pectin values. Any Delicious apples picked mature or overmature will eventually become mealy, the more mature they are at picking, the more likely they are to become mealy early in their storage life. Delicious ripen very fast at room temperatures becoming eating ripe two weeks from picking when held at 60° F. Three weeks from picking at 60° F. they are often turning mealy. Prompt cold storage greatly checks ripening; six to seven weeks from picking are required for the fruit to ripen to prime condition at 40° F., and nine to twelve weeks at 32° F. Delayed storage for this variety is disastrous, for the apples soften as much in three weeks on the packing house floor as they do in three months at 32° F. At 40° F. they soften as much in three months as they do in six months at 32° F. A mealy Delicious apple is not an attractive fruit to eat at any time, but is usually doubly objectionable since it also possesses a peculiar, stale, musty, aldehydic flavor particularly characteristic of the variety. A physiological investigation into the nature of the substance producing this overripe flavor in Delicious would be an interesting contribution to knowledge.

Controlling and delaying development of mealiness in Delicious apples depends upon treatments which inhibit ripening. Storage of Delicious in a controlled atmosphere of 2.5 per cent oxygen and 97.5 per cent carbon dioxide at either 32° or 40° F. markedly retarded ripening of the fruit. The low oxygen content of this atmosphere produced the beneficial effect without impairing fruit flavor. A mixture with similar oxygen content, but with the addition of 5 per cent of carbon dioxide gave results nearly as good. However, when carbon dioxide was present in the atmosphere in amounts from 5 to 10 per cent, in the presence of 10 to 25 per cent of oxygen, softening of fruit and development of mealiness was actually more rapid than in plain air at the same temperature. The fact that 5 per cent of carbon dioxide with 2.5 per cent oxygen gave results superior to storage in air appears to indicate that with low oxygen carbon dioxide did not produce any very marked deleterious effects. Further investigation into the composition of the internal atmosphere of fruits given different controlled atmosphere treatments would probably provide useful information. Waxing of Delicious improved keeping quality, but the reason for this is difficult to explain on the basis of the carbon dioxide - oxygen relationships just discussed.

The physiological changes associated with ripening in the Delicious variety are dealt with in some detail.

Emphasis is laid upon the fact that mealiness in this variety is not associated with depletion of food reserves, but rather with hydrolysis of protopectin materials to the soluble pectin form. The soluble pectin content of the juice seemed a good index of stage of ripeness. Changes in starch content of the fruit during ripening, as judged by the starch-iodine reaction, show promise as a means of evaluating keeping life of apples stored at different temperatures. By comparing samples with the photographs in Figure 4 it may be judged how long such samples may safely be expected to keep in good condition.

An important aspect of the Delicious storage problem which needs investigation is the relative merits of red strains of Delicious as compared with the standard striped strain with particular reference to mealiness, quality, and storage life.

V. CONCLUSIONS

1. Orchard conditions and seasonal variations markedly influence the quality of Delicious apples.

2. Quality of Delicious apples is frequently marred by harvesting the fruit in an immature condition.

3. Delicious apples harvested at the correct stage of maturity to ensure development of superior quality, are likely to go mealy in a short time unless care is taken to provide proper storage conditions.

4. Immediate storage of Delicious at 32° F. is necessary to ensure longest keeping life.

5. Storage at higher temperatures or following periods of delay at high temperatures greatly reduces storage life.

6. Decrease in starch content and increase in soluble pectin content are reliable physiological tests for ripening in Delicious after the fruit has been picked and placed in storage.

7. Storage of Delicious apples in atmospheres containing 2.5 per cent oxygen and 97.5 per cent nitrogen at 32° F. or 40° F. inhibits softening, retards changes in ground color of skin, and greatly increases storage life as compared with air stored checks held at 32° F. Moreover, such treatment results in no undesirable flavor or aroma,

and in no tendency toward loss of ability to ripen with characteristic Delicious quality when the fruit is removed from storage.

8. Storage of Delicious apples in atmospheres containing 5 per cent carbon dioxide with oxygen above the 10 per cent level causes the apples to become mealy, whereas 5 per cent carbon dioxide with 2.5 per cent oxygen does little harm.

9. Chemical composition of Delicious apples stored in controlled atmospheres differs significantly from air-stored checks only in reduced rate of protopectin hydrclysis.

VI. SUMMARY

This investigation dealing with harvesting and storage of Delicious apples has been in progress since 1937. A great volume of fruit has been examined from growers' orchards, and from commercial cold storage plants of the apple growing districts of the Okanagan Valley of British Columbia. One year's work was carried out in Iowa with Iowa-grown Delicious. The studies have involved harvesting tests, different methods of storage, and physiological tests for recognizing and evaluating the progress of ripening in stored fruit. Controlled atmosphere storage for Delicious has been investigated in both Iowa and British Columbia. Chemical determinations of changes involved during the ripening of Delicious apples under different treatments are presented. The results are summarized as follows:

1. Delicious apples harvested in different orchards in different districts showed great variability in quality, maturity, firmness, and keeping quality.

2. Apples picked immature never developed true Delicious flavor, but seldom turned mealy, even after prolonged storage; apples picked mature had good flavor, but tended to become mealy soon after ripening unless stored immediately at 32° F.; when overripe both mature and immature

Delicious acquired a stale disagreeable flavor.

3. Seasonal weather conditions greatly influenced quality in Delicious. In the cool season of 1939 maturity and quality were generally poor; in the hot season of 1940, excellent.

4. The starch-iodine reaction as a picking guide for Delicious is discussed but not fully recommended. Starch decreased slowly in Delicious until the final picking when a large loss was noted.

5. In the period preceding harvesting maturity, changes in sugars and acid were found to be very small in amount.

6. Delicious ripened about three times as fast at 60° F. as at 40° F., and about 1.6 times as fast at 40° F. as at 32° F. as judged by organoleptic tests.

7. After harvest Delicious become eating ripe in two weeks at 60° F.; in six to seven weeks at 40° F.; and in nine to twelve weeks at 32° F. Delicious apples were mealy and overripe in five to six weeks from picking when held at 60° F., in fifteen to sixteen weeks when held at 40° F., and in twenty-four to twenty-seven weeks when held at 32° F. At 32° F., the best temperature for storing Delicious, this variety should not be stored longer than sixteen weeks.

8. Delayed storage, where Delicious were held for

periods of one, two, and three weeks prior to placing in cold storage, greatly reduced subsequent storage life.

9. Delicious softened as much in three weeks at 60° F. as in three months at 32° F. At 40° F. Delicious softened as much in three months as apples stored at 32° F. for six months. Fruit removed from cold storage later than February did not soften much further.

10. When removed from cold storage Delicious apples which had been cold stored immediately were superior in flavor to those given delayed storage.

11. In Delicious held at 60° F., respiration intensity reached its climacteric about five days after picking; fruit stored at 40° and 32° F. showed no distinct climacteric.

12. Respiration rate at 60° F. was double that at 40° F. and three times that at 32° F. Sugar losses through respiration during the storage life of the fruit amounted to roughly 1 per cent of the fresh weight at picking.

13. Hydrolysis of protopectin to soluble pectin in Delicious apples closely paralleled rate of ripening at different temperatures.

14. Disappearance of starch as judged by the starch-iodine reaction proved a reliable index of degree of ripening in storage at different temperatures. For this purpose, a set of eight photographed standards is presented showing

progressive decrease in starch content of Delicious apples during ripening.

15. Delicious stored in "natural build-up" carbon dioxide concentrations of 5.0, 7.5, and 10.0 per cent at 32° and 40° F. actually became mealy faster than similar fruit stored in air.

16. These atmospheres induced heavy development of a peculiar type of skin scald, especially at 40° F.

17. Storage of Delicious apples in an atmosphere of 2.5 per cent oxygen and 97.5 per cent nitrogen at 40° and 32° F. retarded softening, inhibited changes in ground color of skin, and greatly improved keeping quality over fruit stored in air at 32° F. When removed from storage in February, soluble pectin values of the fruit were about the same as at time of picking. Keeping life at 60° F. was prolonged at least ten days as compared with similar fruit stored in air at 32° F.

18. An atmosphere of 2.5 per cent oxygen, 5.0 per cent carbon dioxide, and 92.5 per cent nitrogen gave nearly as good results as the 2.5 : 97.5 oxygen-nitrogen mixture.

19. Storage of Delicious in an atmosphere containing 25.0 per cent oxygen, 5.0 per cent carbon dioxide, and 70.0 per cent nitrogen caused the fruit to go mealy and ripen more rapidly than in air.

20. Much greater differences in storage life of

Delicious were noted between 32° and 40° F. storage in air, than between 32° and 40° F. storage in controlled atmospheres.

21. The only significant changes in chemical composition of fruit stored in controlled atmospheres as compared with air, involving analyses for sugars, starch, acid, and pectin, were the differences in degree of protopectin hydrolysis, which reflected the amount of softening which had taken place.

22. Waxing of Delicious apples with a commercial brand of wax emulsion delayed development of mealiness, improved storage life, but resulted in the appearance of a peculiar type of skin scald differing somewhat from typical apple scald.

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IX. VITA

I was born on February 3, 1914, in Kelowna, British Columbia, Canada, the son of the late Guy Arnold Fisher and Mrs. G. A. Fisher (née Jessie Gibbons Vince). Elementary and secondary education were received at the Kelowna Public and Kelowna High Schools.

First year university work was taken at Kelowna High School, and I completed my undergraduate course at the University of British Columbia receiving the degree of Bachelor of Science in Agriculture in 1933. For this degree the field of specialization was Horticulture with Dr. Alden F. Barss in charge of major work.

After receiving a position at the Dominion Experimental Station, Summerland, B. C., leave of absence was granted for me to pursue graduate studies at the University of British Columbia. From that University I received the M.S.A. degree in 1936, majoring in Horticulture under Dr. G. H. Harris and Dr. A. F. Barss, and minoring in genetics under Dr. G. G. Moe and Dr. A. H. Hutchinson.

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